Concrete Overlays for Pavement Rehabilitation

Reported by ACI Committee 325

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Keywords: bond; concrete; joint; overlay; pavement (concrete); rehabilitation; repair.

This report provides information on the use of concrete overlays for rehabilitation of both concrete (rigid) and asphalt (flexible) pavements. Selection, design, and construction of both bonded and unbonded overlays are discussed. The overlay categories reviewed include bonded concrete overlays, unbonded concrete overlays, whitetopping overlays, and concrete overlays bonded to asphalt (ultra-thin and thin whitetopping). Information is also provided on selecting overlay alternatives. Significant portions of this document are based on a synthesis report prepared for the Federal Highway Administration (FHWA) by Applied Pavement Technology, Inc., under contract number DTFH61-00-P-00507. The report, “Portland Cement Concrete Overlays: State of the Technology Synthesis,” is available from the FHWA as publication FHWA-IF-02-045.

Contents

Chapter 1—Introduction, p. 325.13R-2
1.1—Background
1.2—Purpose of report
1.3—Definitions and notation

Chapter 2—Concrete overlay types and construction materials, p. 325.13R-4
2.1—Introduction
2.2—Types of concrete overlays
2.3—Overlay materials
2.4—Interface materials
2.5—Incidental materials
2.6—Concrete production, construction, and quality-control issues

Chapter 3—Selection of concrete overlay alternatives, p. 325.13R-11
3.1—Introduction
3.2—Effectiveness of different types of concrete overlays
3.3—Selection process

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Chapter 4—Bonded concrete overlays, p. 325.13R-13
4.1—Introduction
4.2—Design
4.3—Construction

Chapter 5—Unbonded concrete overlays, p. 325.13R-18
5.1—Introduction
5.2—Design
5.3—Construction
5.4—Performance

Chapter 6—Conventional whitetopping overlays, p. 325.13R-25
6.1—Introduction
6.2—Design
6.3—Construction
6.4—Performance

Chapter 7—Ultra-thin and thin whitetopping overlays, p. 325.13R-30
7.1—Introduction
7.2—Design
7.3—Construction
7.4—Performance

Chapter 8—References, p. 325.13R-35
8.1—Referenced standards and reports
8.2—Cited references

CHAPTER 1—INTRODUCTION

1.1—Background
Hydraulic cement concrete overlays are used as a rehabilitation technique for both existing concrete and asphalt pavements. Concrete overlays offer the potential for extended service life, increased structural capacity, reduced maintenance requirements, and lower life-cycle costs when compared with hot-mix asphalt overlay alternatives.

Concrete overlays have been used to rehabilitate existing concrete pavements since 1913 and to rehabilitate existing asphalt pavements since 1918 (Hutchinson 1982). Beginning around the mid-1960s, many highway agencies began to search for alternative means of rehabilitating existing pavements, and the use of concrete overlays increased significantly (McGhee 1994). In the 1990s, there was an even higher increase in the use of concrete overlays, spurred by improvements in concrete paving technology. For example, the use of zero-clearance pavers, fast-track paving concepts, and high-early-strength concrete mixtures greatly increased the ability of concrete overlays to serve as a viable rehabilitation alternative.

Parallel with the increased use of concrete overlays, significant research aimed at advancing the state of the knowledge of concrete overlays was conducted. One impetus for this research was the Intermodal Surface Transportation Act (ISTEA) of 1991, which included a provision under Section 6005 allocating designated funding for the assessment of thin bonded concrete overlays and surface lamination technology. The goals of the assessment were to evaluate the feasibility, costs, and benefits of the techniques in minimizing overlay thickness, initial laydown costs, and time out of service, and also to maximize life-cycle durability. As part of this effort, the Federal Highway Administration (FHWA) participated in funding 12 test-and-evaluation projects throughout the country (Sprinkel 2000).

Other examples of ongoing studies of concrete overlays are those being conducted under the FHWA’s Long-Term Pavement Performance (LTPP) program. The LTPP program is divided into two complementary studies: the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). Under GPS-9, the performance of unbonded concrete overlays is being investigated; currently, 14 projects are being evaluated. Under SPS-7, the performance of four bonded overlay projects is being studied. The long-term monitoring of these GPS and SPS projects is expected to provide valuable information on the design and construction of concrete overlays. Additional information may be obtained by visiting the LTPP website at www.fhwa.dot.gov/pavement/ltpp/ltpp.htm.

Resurfacing asphalt pavements with concrete overlays, a process known as whitetopping, is another example of overlay research. In particular, several studies on the use of ultra-thin whitetopping (UTW), a very thin (2 to 4 in. [50 to 100 mm]) layer of concrete bonded to an existing asphalt pavement, have been conducted. In the 1990s, this technique evolved from a radical rehabilitation concept to a mainstream rehabilitation alternative. Several studies on whitetopping overlays are currently being conducted by the FHWA. Additional information may be obtained at www.fhwa.dot.gov/pavement/utwweb/utw.htm.

1.2—Purpose of report
Two ACI Committee 325 reports (ACI Committee 325 1958, 1967) discussed the pioneering work by the U.S. Army Corps of Engineers to develop design procedures for concrete overlays. The equations developed by the Corps for bonded, partially bonded, and unbonded concrete-on-concrete overlays are still used. The report suggested the design of concrete overlays on flexible pavement using the flexible pavement as a stiff base.

During the 1980s and 1990s, two National Cooperative Highway Research Program (NCHRP) syntheses were prepared on concrete overlays: “Resurfacing with Portland Cement Concrete” (Hutchinson 1982), and “Portland Cement Concrete Resurfacing” (McGhee 1994). There has been considerable work, however, in the area of concrete overlays since the most recent NCHRP synthesis. There is a need to assemble and synthesize information on the selection, design, and construction of concrete overlays for pavement rehabilitation.

This report discusses the selection, design, construction, and performance of concrete overlays. It is intended to provide the current state of the technology (as of 2004) of concrete overlays of both existing concrete pavements and existing asphalt pavements.

1.3—Definitions and notation
1.3.1 Definitions—This section presents definitions and notations unique to this report. Additional definitions for
common concrete terminology can be found in ACI 116R. Definitions shown in italics are terms that may be found in ACI 116R, but have been redefined for this report.

**break and seat**—technique similar to crack and seat, except conducted on jointed reinforced concrete pavements and using higher impact energy; uses more impact energy to rupture the steel or break its bond with the concrete to ensure independent movement, and seating with a heavy roller.

**crack and seat**—technique involving fracturing the existing jointed plain concrete pavements into pieces 1 to 4 ft (0.3 to 1.2 m) on a side by inducing full-depth cracks using a modified pile driver, guillotine hammer, whip hammer, or other equipment, and seating with a heavy roller.

**curling**—concrete distortion, usually in a slab, resulting from differential temperatures.

**drainage, subsurface**—inclusion of specific drainage elements in a pavement structure intended to remove excess surface infiltration water from a pavement.

**equivalent single-axle loads (ESALs)**—summation of 18 kip (80 kN) single-axle load applications used to combine mixed traffic to design traffic during the analysis period.

**falling weight deflectometer**—device in which electronic sensors measure the deflection of the pavement as a result of an impact load of known magnitude; results can be used to estimate the elastic moduli of subgrade and pavement layers and the load transfer across joints and cracks.

**faulting**—difference of elevation across a joint.

**fracturing, slab**—technique in which an existing portland-cement concrete pavement is cracked or broken into smaller pieces to reduce the likelihood of reflection cracking.

**hot-mix asphalt (HMA)**—an asphalt cement-aggregate mixture that is mixed, spread, and compacted at an elevated temperature; also commonly referred to as “asphalt concrete” or “asphalt.”

**joint orientation**—alignment of transverse joints in a concrete pavement with respect to the centerline of the pavement.

**layer, separator**—layer of hot-mix asphalt, bituminous material, or other stress-relieving material used at the interface between an unbonded concrete overlay and the existing concrete pavement to ensure independent behavior.

**leveling course**—thin layer of hot-mix asphalt or other bituminous material to produce a uniform surface for paving.

**load transfer**—means through which wheel loads are transferred or transmitted across a joint from one slab to the next.

**life-cycle cost analysis (LCCA)**—economic assessment of competing pavement design alternatives in which all significant costs over the life of each alternative are considered. LCCA is used to evaluate a design solution. Life-cycle costs may be measured for different designs to determine which design will meet the economic and performance goals.

**mill**—process using drum-mounted carbide steel cutting bits to remove material from a pavement and provide texture to promote bonding with an overlay.

**overlay, bonded concrete**—hydraulic cement concrete overlay bonded directly to an existing concrete pavement to form a monolithic structure.

**overlay, partially bonded**—hydraulic cement concrete overlay that is placed directly on an existing portland-cement concrete pavement with little or no surface preparation; consequently, partial bonding between the two pavements is expected.

**overlay, unbonded concrete**—hydraulic cement concrete overlay placed on an existing distressed concrete pavement such that the overlay is separated from the existing pavement through a separator layer.

**pavement, continuously reinforced concrete (CRCP)**—pavement with uninterrupted longitudinal steel reinforcement and no intermediate transverse expansion or contraction joints.

**pavement, jointed plain concrete (JPCP)**—hydraulic cement concrete pavement system characterized by short joint spacings and no distributed reinforcing steel in the slab, with or without dowels.

**pavement, jointed reinforced concrete (JRPC)**—hydraulic cement concrete pavement system containing dowels, characterized by long joint spacings and distributed reinforcing steel in the slab to control crack widths.

**repair, preoverlay**—repair or renovation activity performed on an existing pavement before the placement of an overlay.

**roughness**—irregularities in the pavement surface that adversely affect ride quality, safety, and vehicle maintenance costs.

**rubblize, rubblization**—breaking the existing pavement into pieces no larger than 6 in. (150 mm) on a side using a vibratory beam breaker or resonant frequency pavement breaker.

**shotblasting**—surface preparation technique in which steel shots are propelled against the surface of a portland-cement concrete pavement, effectively cleaning and preparing the surface to receive a bonded concrete overlay.

**slab, shattered**—concrete pavement with extensive longitudinal and transverse cracking.

**slab, widened**—concrete pavement slab that is paved wider (usually at least 18 in. [450 mm] wider) than a conventional 12 ft (3.7 m) traffic lane to increase the distance between truck tires and slab edge, thereby reducing edge stresses due to loading.

**stripping**—separation of asphalt cement from aggregate due to moisture attack.

**user costs**—in a life-cycle cost analysis, costs incurred by the user, such as delay costs, vehicle operating costs, and accident costs.

**variable joint spacing**—series of different joint spacings repeated in a regular pattern intended to reduce the rhythmic response of vehicles traveling over uniformly spaced joints.

**warping**—concrete distortion caused by differential moisture.

**whitetopping**—concrete overlay placed on an existing asphalt pavement. Whitetopping may be used in referring to conventional whitetopping, thin whitetopping, or ultra-thin whitetopping.

**whitetopping, conventional**—overlay placed on asphalt pavement, typically with a thickness higher than 8 in. (200 mm).

**whitetopping, thin**—bonded concrete overlay of thickness between 4 and 8 in. (100 and 200 mm) and typically having a joint spacing between 6 and 12 ft (1.8 and 3.7 m) that is placed on milled asphalt pavement.
**whitetopping, ultra-thin (UTW)—bonded concrete overlay of thickness less than 4 in. (100 mm) and typically having a joint spacing less than 6 ft (1.8 m) that is placed on a milled asphalt pavement.**

**whitetawching**—application of a lime slurry to an asphalt pavement surface to reduce the surface temperature.

### 1.3.2 Notation—

- **CF** = condition factor estimated based on remaining life (Section 4.2.3.1)
- **D** = actual thickness of existing slab, in. (mm) (Section 4.2.3.1, 5.2.4)
- **D_{eff}** = effective thickness of existing slab, in. (mm) (Section 4.2.3)
- **D_{f}** = required thickness of new concrete pavement for future traffic loadings, in. (mm) (Section 4.2.3.1, 5.2.4)
- **D_{max}** = maximum thickness of slab, in. (mm) (Section 6.3.5)
- **D_{nom}** = nominal thickness of slab, in. (mm) (Section 6.3.5)
- **D_{OL}** = thickness of bonded or unbonded overlay, in. (mm) (Section 4.2.3.1, 5.2.4)
- **E_{c}** = modulus of elasticity of concrete, psi (MPa) (Section 5.2.6)
- **F_{dur}** = durability adjustment factor (Section 4.2.3)
- **F_{fat}** = fatigue damage adjustment factor (Section 4.2.3)
- **F_{jc}** = joint condition adjustment factor for bonded overlays (Section 4.2.3)
- **F_{jcu}** = joint condition adjustment factor for unbonded overlays (Section 5.2.4)
- **k** = modulus of subgrade reaction, psi/in. or lb/in.³ (MPa/mm) (Section 5.2.6, 6.2.2, 7.2.2)
- **t** = radius of relative stiffness, in. (mm) (Section 5.2.6)
- **L** = joint spacing, in. (mm) (Section 5.2.6)
- **L_{max}** = maximum joint spacing, in. (mm) (Section 7.2.5)
- **M_{R}** = resilient modulus (Section 6.2.2, 7.2.2)
- **SC_{eff}** = effective structural capacity of existing pavement (Section 4.2.3.1, 5.2.4)
- **SC_{f}** = structural capacity of new pavement (Section 4.2.3.1, 5.2.4)
- **SC_{O}** = original structural capacity when pavement was first constructed (Section 4.2.3.1)
- **SC_{OL}** = structural capacity of new overlay (Section 4.2.3.1, 5.2.4)
- **\( \mu \)** = Poisson’s ratio (Section 5.2.6)

### Table 2.1—Recommended load transfer designs (Smith and Hall 2001)

<table>
<thead>
<tr>
<th>Design feature</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dowel diameter</td>
<td>Design catalog (Darter et al. 1997)</td>
</tr>
<tr>
<td></td>
<td>&lt;30 million ESALs 1.25 in. (30 mm) bar</td>
</tr>
<tr>
<td></td>
<td>30 to 90 million ESALs 1.5 in. (38 mm) bar</td>
</tr>
<tr>
<td></td>
<td>&gt;90 million ESALs 1.625 in. (41 mm) bar</td>
</tr>
<tr>
<td>Dowel length</td>
<td>18 in. (450 mm)</td>
</tr>
<tr>
<td>Dowel spacing</td>
<td>12 in. (300 mm) center-to-center across the joint</td>
</tr>
<tr>
<td></td>
<td>Alternative: cluster dowels in wheel path (Fig. 2.1)</td>
</tr>
<tr>
<td>Dowel coating</td>
<td>Epoxy</td>
</tr>
</tbody>
</table>

### CHAPTER 2—CONCRETE OVERLAY TYPES AND CONSTRUCTION MATERIALS

#### 2.1—Introduction

This chapter presents general information on the different types of concrete overlays that are typically used in pavement rehabilitation and some of their common features. Concrete overlays for both existing concrete and existing asphalt pavements are described, including a summary of their defining characteristics. This chapter serves only as an introduction to the different concrete overlay types; detailed information is presented in later chapters.

Materials used in construction of concrete overlays are also described in this chapter. This includes a summary of concrete paving materials and mixture proportions, as well as interface materials and other aspects of construction.

#### 2.2—Types of concrete overlays

##### 2.2.1 Concrete pavement types—Concrete overlays and existing concrete pavements may be one of three basic types: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). Although in theory any type of concrete pavement could be used for an overlay, in practice, jointed plain concrete pavement (with and without dowels) is by far the most common.

##### 2.2.1.1 Jointed plain concrete pavement—JPCP is a hydraulic cement concrete pavement system characterized by short joint spacings, no distributed reinforcing steel in the slab, and with or without dowels. Maximum slab length is typically 20 ft (6 m). Undoweled or aggregate interlock joints are generally used for short slabs, thin slabs, or both. For most pavements, however, adequately sized dowels should be provided to reduce faulting (Snyder et al. 1989; Smith et al. 1997). Dowel diameter is often selected based on slab thickness, but traffic may be a more important factor for consideration. Recommended load transfer designs are summarized in Table 2.1.

For concrete overlays, the recommended number and spacing of dowels is the same as those for new pavements. In general, uniform 12 in. (300 mm) spacing is recommended, but nonuniform spacing has also been used successfully. In the nonuniform dowel spacing design, the dowels are concentrated in the wheel paths (Darter et al. 1997). One recommended design for variable dowel bar spacing is illustrated in Fig. 2.1.

In general, joints perpendicular to the direction of traffic are recommended. On new JPCP, skewed joints can be effective in reducing faulting on nondoweled pavements, but have no effect when used on properly doweled pavements (Yu et al. 1998a; Khazanovich et al. 1998). Furthermore, JPCP designs with skewed joints constructed on a stiff base (treated cement or lean concrete) are prone to corner breaks.
Concrete overlays of existing concrete pavements are generally classified according to the proposed bonding condition between the new overlay and the existing pavement. They may be placed in a bonded, partially bonded, or unbonded condition, the selection of which depends largely upon the condition of the existing pavement and on the future traffic levels. Table 2.2 summarizes some key characteristics of each of these concrete overlay types (Hoerner et al. 2001).

2.2.1.2 Jointed reinforced concrete pavement—JRCP is a hydraulic cement concrete pavement system containing dowels, characterized by long joint spacings and distributed reinforcing steel in the slab to control crack widths. Slab lengths are generally more than 20 ft (6 m), and may be as much as 60 ft (18 m). Current pavement practice is away from JRCP designs, and construction is rare because the longer joint spacing results in more joint movement. When midslab cracks occur, the light reinforcing may not be enough to hold the cracks tightly. If JRCP is used, the recommended maximum joint spacing is 30 ft (9 m) (FHWA 1990). Deformed bars or deformed welded wire reinforcement are recommended at a minimum steel content of 0.19% (Darter et al. 1997).

2.2.1.3 Continuously reinforced concrete pavement—CRCP, also known as continuous concrete pavement, is a pavement with uninterrupted longitudinal steel reinforcement and no intermediate transverse expansion or contraction joints. Reinforcement design for CRCP overlays is similar to that for new design. The recommended minimum steel content is 0.60%, and the use of deformed bars is strongly recommended (Darter et al. 1997). The depth of reinforcing steel has a significant effect on crack opening, and steel placement closer to the top surface may provide tighter cracks and better long-term performance (Dhamrait and Taylor 1979; Roman and Darter 1988). A minimum concrete cover of 2.5 in. (65 mm) is recommended for protection of the reinforcing steel against corrosion.

2.2.2 Concrete overlays of existing concrete pavements—Concrete overlays of existing concrete pavements are generally classified according to the proposed bonding condition between the new overlay and the existing pavement. They are used to increase the structural capacity of an existing pavement or to improve its overall ride quality, and should be used where the underlying pavement is free of structural distress and in relatively good condition (ACPA 1990a; McGhee 1994). Perhaps the most important construction and performance aspect of bonded overlays is achievement of an effective bond between the overlay and existing pavement. This is necessary to create a pavement system that behaves monolithically; if such bonding is not achieved, cracking of the overlay will result due to increased curling, warping, and loading stresses. Surface preparation of the existing concrete pavement is required to produce a clean, roughened surface that will promote bonding between the two layers. This is commonly accomplished using shotblasting, milling, or hydroblasting equipment.

Bonded overlays have been constructed in many states, including California, Illinois, Iowa, Louisiana, New York, Pennsylvania, South Dakota, Texas, and Virginia, and in the countries of Belgium, Canada, Japan, and Sweden. By far the most common bonded overlay type is JPCP, and this has been placed on existing JPCP, JRCP, and CRCP designs (McGhee 1994). Some jointed and reinforced bonded overlays have been used on existing JPCP and JRCP, although presently, they are rarely used. Texas and Virginia have both constructed several bonded overlays on existing CRCP.

### Table 2.2—Summary of concrete overlays of existing concrete pavements (adapted from Hoerner et al. 2001)

<table>
<thead>
<tr>
<th>How bonding condition is achieved</th>
<th>Condition of existing pavement</th>
<th>Preoverlay repair</th>
<th>Special design and construction considerations</th>
<th>Overlay types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonded</td>
<td>Relatively good condition</td>
<td>All deteriorated cracks, joints, and punchouts</td>
<td>Achieving bond between two concrete layers</td>
<td>JPCP</td>
</tr>
<tr>
<td>Partially bonded</td>
<td>No materials-related distress</td>
<td>Most deteriorated cracks, joints, and punchouts</td>
<td>Matching joints of overlay with those in existing pavement</td>
<td>JRCP</td>
</tr>
<tr>
<td>Unbonded</td>
<td>Fair to moderate condition</td>
<td>Limited repair</td>
<td>Achieving separation between two concrete layers</td>
<td>CRCP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typical thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 to 4 in. (75 to 100 mm)</td>
</tr>
<tr>
<td>6 to 8 in. (150 to 200 mm)</td>
</tr>
<tr>
<td>6 to 12 in. (150 to 300 mm)</td>
</tr>
</tbody>
</table>

**Fig. 2.1**—Recommended design for variable dowel bar spacing (Darter et al. 1997).
2.2.2.2 Partially bonded concrete overlays—Partially bonded concrete overlays are placed directly on existing concrete pavements with little, if any, surface preparation. These are used when the degree of bonding is not critical to the performance of the overlay (Lokken 1981). Partially bonded overlays are more commonly used on airfield pavement where a thicker overlay is required because of heavy aircraft loads, and where the slabs are more fully restrained. On airfield pavements, partially bonded overlay thicknesses are generally higher than 12 in. (300 mm), whereas on highway applications, thicknesses are generally in the range of 6 to 8 in. (150 to 200 mm).

As previously mentioned, no special measures are taken to either promote or prevent bond. As a result, varying degrees of bonding will occur, so reflection cracking is a potential problem. Consequently, partially bonded overlays should be used only when the existing concrete pavement is in a sound, well-seated condition and with no major distresses, distortions, or rocking slabs (Lokken 1981).

According to the comprehensive list of concrete overlay construction projects prepared by McGhee (1994), most partially bonded overlays are either JPCP or JRCP designs, although a few CRCP designs have been constructed. That same list, however, also shows that partially bonded overlays are not widely used for highway applications.

2.2.2.3 Unbonded concrete overlays—An unbonded concrete overlay (sometimes called a separated overlay) contains an interlayer between the existing pavement and the new overlay (Fig. 2.3). This separation layer is placed to ensure independent behavior between the two slabs, thereby minimizing the potential for reflection cracking. Unbonded overlays are typically between 6 and 12 in. (150 and 300 mm) thick.

Unbonded concrete overlays are used when the existing pavement deterioration is so advanced that it cannot be effectively corrected before overlaying (ACPA 1990b). Because the two pavements will be separated, little preoverlay repair is typically required. The separator layer should be effective at ensuring independent behavior between the two rigid layers. Hot-mix asphalt layers (typically approximately 1 in. [25 mm] thick) are commonly used as an interlayer.

In both highway and airfield applications, unbonded overlays have seen far greater use than either bonded or partially bonded overlays. Most unbonded overlays have been jointed plain concrete designs, although a significant number of unbonded continuously reinforced concrete designs have been used.

2.2.3 Concrete overlays of existing asphalt pavements—Whitetopping, the use of concrete overlays of existing asphalt pavements, increased considerably in the 1990s. These overlays are generally classified as conventional, thin, or ultra-thin whitetopping, according to the thickness of the concrete overlay. Table 2.3 summarizes some of the key characteristics of the conventional whitetopping and ultra-thin whitetopping (UTW) concrete overlay types (Grogg et al. 2001).

2.2.3.1 Conventional whitetopping—Conventional whitetopping is the placement of a concrete overlay on an existing asphalt pavement. These are generally designed as new concrete pavement structures, and can range from 4 to 12 in. (100 to 300 mm) thick, although they are typically at least 8 in. (200 mm) thick. A typical cross section of a whitetopped pavement is shown in Fig. 2.4 (McGhee 1994). The interface shown may be on a milled surface, on a hot-mix asphalt leveling course, or may have no treatment at all (direct placement).

Conventional whitetopping is an alternative solution to hot-mix asphalt for rehabilitating deteriorated flexible pavements that exhibit such distresses as rutting, shoving, and alligator cracking (ACPA 1998). Preoverlay repair of badly distressed or failed areas is required, and many agencies cold mill the existing asphalt surface to remove ruts or surface irregularities before placing the overlay (McGhee 1994).

A conventional whitetopping overlay is designed essentially as a new concrete pavement on a treated base course, assuming an unbonded condition between the layers. Some partial bonding between the overlay and existing asphalt pavement can occur, however, which can contribute to the performance of the pavement. Conventional whitetopping has been designed as jointed plain concrete overlays (most common), jointed reinforced concrete overlays (rarely used), and continuously reinforced concrete overlays.
Table 2.3—Summary of whitetopping and ultra-thin whitetopping overlays (Grogg et al. 2001)

<table>
<thead>
<tr>
<th></th>
<th>Conventional whitetopping</th>
<th>Ultra-thin whitetopping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical thickness</td>
<td>• 8 to 12 in. (200 to 300 mm)</td>
<td>• 2 to 4 in. (50 to 100 mm)</td>
</tr>
<tr>
<td>Condition of existing pavement</td>
<td>• All deteriorated hot-mix asphalt pavements</td>
<td>• Low-volume deteriorated hot-mix asphalt pavements (particularly in areas where rutting is a problem)</td>
</tr>
<tr>
<td>Bonding condition</td>
<td>• Designed as unbonded, but some partial bonding occurs (and may enhance pavement performance)</td>
<td>• Strong bond required between existing hot-mix asphalt pavement and new concrete overlay</td>
</tr>
<tr>
<td>Preoverlay repair</td>
<td>• Limited repair (failed areas only)</td>
<td>• Repair of areas unable to contribute to load-carrying capacity</td>
</tr>
<tr>
<td>Minimum thickness of hot-mix asphalt</td>
<td>• 2 in. (50 mm) (after any milling)</td>
<td>• 3 to 6 in. (75 to 150 mm) (after any milling)</td>
</tr>
<tr>
<td>Special design and construction considerations</td>
<td>• Adequate support critical to performance</td>
<td>• Bonding with hot-mix asphalt pavement</td>
</tr>
<tr>
<td></td>
<td>• Adequate joint design (including joint spacing and load transfer)</td>
<td>Concrete mixture proportioning is often high-strength, fiber-modified, or both</td>
</tr>
<tr>
<td></td>
<td>• Placement of a whitewash on hot-mix asphalt surface on hot days</td>
<td>Extremely short joint spacings (typically between 2 and 6 ft [0.6 and 1.8 m])</td>
</tr>
<tr>
<td>Concrete overlay types</td>
<td>• JPCP</td>
<td>• JPCP</td>
</tr>
<tr>
<td></td>
<td>• JRCP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• CRCP</td>
<td></td>
</tr>
</tbody>
</table>

2.2.3.2 Ultra-thin and thin whitetopping—UTW and thin whitetopping overlays are both designed assuming that the overlay bonds to the existing asphalt. Most overlays in this category are UTW, although there have been a few thin whitetopping projects constructed; this is an area of increasing research interest. Thin whitetopping represents an extension of the UTW to thicker overlays for pavements carrying heavier traffic.

UTW is a process in which a thin layer of concrete (between 2 and 4 in. [50 and 100 mm] thick) is placed over a rutted or cracked asphalt pavement (ACPA 1998). In a UTW project, the existing hot-mix asphalt surface is cold milled to enhance the bond between the concrete overlay and the pavement to create a monolithic structure. Milling also removes surface irregularities and provides a more uniform surface for overlay placement.

UTW was originally intended for parking lots, residential streets, low-volume roads, general aviation airports, and hot-mix asphalt intersections where rutting is a problem but no other significant structural deterioration is present (ACPA 1998). Since the mid-1990s, its use has been extended to highway applications in Alabama, Kansas, Missouri, and other states.

UTW overlays employ short slabs, typically square and with joint spacing between 2 and 6 ft (0.6 and 1.8 m). This is to help reduce bending and thermal curling stresses. Figure 2.5 shows a schematic of a UTW overlay (Grogg et al. 2001).

The use of UTW grew rapidly during the 1990s, with over 200 projects in 35 states since 1992 (ACPA 2000a). As of 2003, Tennessee had constructed the most UTW projects, followed closely by Kentucky and Kansas. All UTW projects have been jointed, plain concrete overlay designs, but some have used fiber-reinforced concrete (FRC).

Thin whitetopping overlays are between 4 and 8 in. (100 and 200 mm) thick concrete slabs with joint spacing between 6 and 12 ft (1.8 and 3.7 m) that are placed on a milled asphalt pavement. As with the UTW design, milling of the asphalt surface is intended to promote bonding between the overlay and the existing pavement. This bonding is accounted for in design, and improves the performance of the overlay. Thin whitetopping overlays have been used by a few highway agencies, primarily on state highways.

An inlay is a variation of UTW and thin whitetopping overlays where one or more of the travel lanes of an existing pavement are milled, and the concrete overlay is placed in that milled area. This technique has the advantages of targeting only the distressed lanes, maintaining existing pavement elevations, and eliminating the need for any unnecessary shoulder work or repair. A 6 in. (150 mm) thick thin whitetopping inlay was placed in October 2001 on U.S. 78 in Jasper, Ala. (Delatte et al. 2001).

2.2.3.3 Summary of whitetopping overlay characteristics—The following design and construction characteristics can be used to distinguish between the various types of whitetopping overlays:

- Conventional whitetopping is designed essentially as a new pavement on a stabilized base and assumes an unbonded condition between the concrete overlay and the pavement, even if the pavement is milled. Conventional whitetopping can be used on any type of pavement facility;
- Thin whitetopping is a moderately thin concrete overlay (thicknesses between 4 and 8 in. [100 and 200 mm]) that is placed on a milled asphalt pavement. Bond between concrete overlay and asphalt pavement is considered in design, and short joint spacing (between 6 and 12 ft [1.8 and 3.7 m]) is used. Thin whitetopping overlays have been used most often on state highways and secondary routes; and
UTW is similar in concept to thin whitetopping in that the overlay is bonded to a milled asphalt surface, and bonding is considered in the design. The concrete overlay thicknesses are between 2 and 4 in. (50 and 100 mm), and square slabs (between 2 and 6 ft [0.6 and 1.8 m] in plan) are used. FRC is commonly used. UTW overlays are commonly used on urban streets and intersections.

2.2.4 Other concrete overlay types—A review of the available literature reveals several other types of concrete overlays that have been used. These primarily include fiber-reinforced overlays and prestressed-concrete overlays. These, however, represent changes to the concrete mixture or pavement construction method, and do not alter the way of classifying overlays into the existing categories already defined.

Prestressed overlays have seen limited use in the U.S., and are not discussed in this report. FRC overlays have been used since the 1950s, and have since seen an increase in use as part of many UTW projects. Some additional information on the use of fiber in concrete is presented in ACI 544.1R.

2.3—Overlay materials
This section describes materials used in overlays. Conventional portland cement concrete is by far the most commonly used paving surface material, although other hydraulic cements and fiber-reinforced portland cement concretes are also used to construct overlays.

2.3.1 Portland and hydraulic cement concrete—Conventional concrete paving mixtures are typically used to construct overlays. As with conventional concrete pavements, properly proportioned mixtures are essential to satisfactory performance. Each of the components used in a concrete mixture should be carefully selected so that the resulting mixture is dense, relatively impermeable, and resistant to both environmental effects and deleterious chemical reactions over its service life (Van Dam et al. 2002). Additional information on mixture proportioning can be found in ACI 211.1, 211.2, 211.3R, 211.4R, 211.5R, and PCA’s “Design and Control of Concrete Mixtures” (2002).

As with conventional concrete pavements, Type I and II cements are commonly used in concrete mixtures for overlays. In situations where high early strength is desired, some agencies use Type III cement, which may have a slightly different chemical composition, and is more finely ground to promote the development of high early strength. Depending on the mixture proportion and strength requirements, cement contents are typically in the range of 500 to 700 lb/ycd³ (295 to 415 kg/m³), although higher contents are sometimes used. For more information about types of cement, refer to ASTM C 150, C 595, and C 1157, and ACI 225R.

Aggregates used in paving concrete range from stone to gravel and glacial deposits (McGhee 1994). To help ensure the longevity of the pavement, these aggregates should not only possess adequate strength, but should also be physically and chemically stable within the concrete mixture (Van Dam et al. 2002). Consequently, extensive laboratory testing or demonstrated field performance is often required to ensure the selection of a durable aggregate. Many agencies use ASTM C 1260 to evaluate aggregates for alkali-silica reaction (ASR). ACI 221.1R contains more information on ASR.

The maximum coarse aggregate size permitted in concrete mixtures is a function of the pavement thickness or the amount of reinforcing steel (if used) (ACI 211.1; PCA 2002). The largest and most practical maximum coarse aggregate size should be used to minimize paste content, reduce shrinkage, minimize costs, and improve mechanical interlock properties at joints and cracks (Van Dam et al. 2002). Although maximum coarse aggregate sizes of 0.75 to 1 in. (19.0 to 25.0 mm) have been common, some agencies are examining the use of larger maximum coarse-aggregate sizes (1.5 to 2 in. [37.5 to 50 mm]) for conventional concrete paving. For thinner overlays (such as bonded concrete or UTW), however, smaller maximum coarse-aggregate sizes are required. For unreinforced pavement structures, the Portland Cement Association (PCA) recommends a maximum aggregate size of one-third of the slab thickness (PCA 2002). For more information on aggregates, refer to ACI 221R and 221.1R.

ACI 211.1 and PCA (2002) provide guidance on the selection of the appropriate water-cementitious material ratio (w/cm). A maximum w/cm of 0.45 is common for pavements in a moist environment and subjected to cycles of freezing and thawing (PCA 2002). Lower w/cm values are used on thinner concrete overlays (bonded overlays and UTW) to accelerate strength gain and to minimize drying shrinkage (McGhee 1994; ACPA 1998). Low water and paste content, however, are more important than the w/cm in minimizing shrinkage.

Various admixtures (ACI 212.3R) are commonly introduced into concrete mixtures:

- Air entrainment protects the hardened concrete from freezing-and-thawing deterioration and deicer scaling and also helps increase the workability of fresh concrete, significantly reducing segregation and bleeding (PCA 2002). Typical entrained air contents of concrete pavement are in the range of 4 to 6%.
- Accelerators increase the rate of concrete strength development. In pavement, they are commonly used in full-depth repairs or on fast-track paving projects in which early opening times are required. Calcium chloride is commonly used as a set accelerator. Nonchloride accelerators should be used if steel reinforcement and dowels are present; and
- Water reducers are added to concrete mixtures to reduce the amount of water required to produce concrete of a given consistency. This allows for a lowering of the w/cm while maintaining a desired slump, and thus has the beneficial effect of increasing strength and reducing permeability (Van Dam et al. 2002).

Supplementary cementitious materials, such as fly ash, slag cement, and silica fume may be used as additions to concrete mixtures. These materials may be placed in addition to the portland cement or as a partial substitution for a percentage of the portland cement. Of these, fly ash is the most commonly used. Fly ash is a by-product of coal-fired power plants, and may be classified as either Class C (high
achieve this, many agencies specify application of a cement grout to the existing concrete pavement just ahead of the bond between the two layers is critical to obtain monolithic behavior of the existing pavement and overlay. To help

Most agencies specify a minimum concrete strength requirement for their pavements. Typical values include compressive and flexural strengths (third-point loading) of 4000 and 650 psi (28 and 4.5 MPa), respectively, at an age of 28 days. Fast-track paving mixtures, using a low w/cm (typically less than 0.43), a higher cement content (typically higher than 650 lb/yt3 [385 kg/m3]), and perhaps a Type III portland cement, rapid-setting hydraulic cement, or chemical-admixture systems have been used by highway agencies to meet opening times of as little as 4 to 8 hours (Hoerner et al. 2001). Fast-track paving technology entails not only the development of fast-setting concrete mixtures, but also the planning and coordination of all construction activities needed to minimize down time (ACPA 1994a; FHWA 1994; ACI 325.11R).

Although the use of fast-track mixtures and paving practices has become more common, there has been some concern regarding the potential detrimental effect of faster-setting cements and reduced construction times on the long-term durability of concrete mixtures (Van Dam et al. 2002). Thus, it may be that both the speed of construction and the long-term concrete durability need to be considered during the mixture proportioning phase of a project.

2.3.2 Fiber-reinforced concrete—FRC is portland cement concrete containing randomly distributed fibers throughout the mixture. The principal reason for incorporating fibers is to increase the toughness of the concrete, which is a measure of its energy-absorbing capacity, and to improve its cracking and deformation characteristics. In some cases, flexural strength may also be increased (PCA 1991).

A wide variety of fiber materials have been used to reinforce concrete; steel, polypropylene, and polyester fibers are most commonly used in the U.S. (PCA 1991). Polyolefin fibers have also been used on several paving projects. ACI 544.1R describes the characteristics of these fibers. Further details are shown in Table 2.4 and provided by Smith et al. (2002).

### Interface materials

Interface materials are used either to enhance the bond between the overlay and the existing pavement (to ensure monolithic behavior) or to separate the overlay from the existing pavement (to ensure independent behavior) (McGhee 1994). Materials commonly used for these applications are described as follows.

#### Bonding agents

For bonded concrete overlays, bond between the two layers is critical to obtain monolithic behavior of the existing pavement and overlay. To help achieve this, many agencies specify application of a cement grout to the existing concrete pavement just ahead of the paver. Cement grouts are generally produced in a mobile mixer from a mixture of portland cement and water; the grout should have a maximum water-cement ratio (w/c) of 0.62 (ACPA 1990a). Before the placement of either type of bonding agent, the pavement surface should have already been prepared and should be surface dry (ACPA 1990a).

Some studies suggest that no bonding agent is necessary for properly prepared surfaces (Whitney et al. 1992; Wells et al. 1999). In addition, there is the possibility that the bonding agent could act as a bond breaker if allowed to dry before the placement of the concrete overlay (ACPA 1990a; Delatte et al. 1998; Sprinkel 2000). Therefore, many practitioners exclude the use of bonding agents.

#### Separator layers

The performance of unbonded concrete overlays over existing concrete pavements depends largely on effective separation between the overlay and existing pavement. Because unbonded concrete overlays are placed on concrete pavements in a more advanced state of deterioration, distresses in the underlying pavement can reflect through the new overlay and compromise its performance.

To minimize the effect of the distresses in the underlying pavement on the performance of the overlay, a separator layer is placed so that the two pavements act independently of each other. Other functions of the separator layer include providing a leveling layer for uniform overlay thickness construction, and providing sufficient friction so that joints and the proper amount of cracks can form in overlays (ERES 1999a).

A wide variety of materials has been used as separator layers, including polyethylene sheeting, wax-based curing compounds, liquid asphalts, and hot-mix asphalt materials (McGhee 1994). The most successful interlayer, and the one most commonly used, is a thick (1 in. [25 mm] or more) layer of hot-mix asphalt (ERES 1999a). Thin asphaltic interlayers, such as chip seals or slurry seals, have worked well in some cases, but are not generally recommended because they do not provide sufficient leveling capabilities, they erode near joints, and they do not effectively separate the two layers (ERES

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#### Table 2.4—Summary of fiber usage in concrete overlays (AASHTO 2000)

<table>
<thead>
<tr>
<th>Location</th>
<th>Year built</th>
<th>Type of overlay</th>
<th>Type of fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-10, Baton Rouge, La.</td>
<td>1990</td>
<td>Bonded</td>
<td>Steel (85 lb/yt3 [50 kg/m3])</td>
</tr>
<tr>
<td>Cherokee County, Okla.</td>
<td>1994</td>
<td>Bonded</td>
<td>Polypropylene (3 lb/yt3 [1.8 kg/m3])</td>
</tr>
<tr>
<td>Beltway 8, Houston, Tex.</td>
<td>1996</td>
<td>Bonded</td>
<td>Steel</td>
</tr>
<tr>
<td>Beltway 8, Houston, Tex.</td>
<td>1999</td>
<td>Bonded</td>
<td>Steel</td>
</tr>
<tr>
<td>Iola, Kans.</td>
<td>2000</td>
<td>Bonded</td>
<td>Polypropylene (3 lb/yt3 [1.8 kg/m3])</td>
</tr>
<tr>
<td>I-29, Atchison County, Mo.</td>
<td>1998</td>
<td>Unbonded</td>
<td>Steel, polyolefin, and polypropylene</td>
</tr>
<tr>
<td>Various projects in Tennessee (Chattanooga, Nashville, Memphis, Knoxville, and others)</td>
<td>1992-present</td>
<td>UTW Polypropylene (3 lb/yt3 [1.8 kg/m3])</td>
<td></td>
</tr>
<tr>
<td>Leawood, Kans.</td>
<td>1995</td>
<td>UTW</td>
<td>Polypropylene (3 lb/yt3 [1.8 kg/m3])</td>
</tr>
<tr>
<td>U.S. Highway 14, Pierre, S. Dak.</td>
<td>1996</td>
<td>UTW</td>
<td>Polyolefin (25 lb/yt3 [15 kg/m3])</td>
</tr>
<tr>
<td>Various street intersections in Springfield, Mass.</td>
<td>1999</td>
<td>UTW</td>
<td>Polypropylene (3 lb/yt3 [1.8 kg/m3])</td>
</tr>
</tbody>
</table>
Tie bars are typically billet steel, Grade 40 (280) or Dowel bars are typically billet steel, Grade 60 (420) in pavement construction, summarized as follows: are essentially the same as used in conventional concrete performance data for these types of interlayers are not available (ERES 1999a).

If the temperature of the hot-mix asphalt interlayer is expected to exceed 110 °F (43 °C) at the time of overlay placement, whitewashing of the surface may be required. The light-colored whitewash reflects sunlight and reduces heat buildup. This reduces the temperature of the interlayer before placement of the concrete overlay, and reduces the risk of shrinkage cracking (ACPA 1990b). Whitewashing may be accomplished using either a lime slurry mixture or a white-pigmented curing compound (ACPA 1990b).

2.5—Incidental materials

Other materials used in the construction of concrete overlays are essentially the same as used in conventional concrete pavement construction, summarized as follows:

- Dowel bars are typically billet steel, Grade 60 (420) bars that conform to ASTM A 615 or AASHTO M 31. The dowel bar size, layout, and coatings should be selected for the specific project location and traffic levels;
- Tie bars are typically billet steel, Grade 40 (280) or Grade 60 (420) bars that meet ASTM A 615 or AASHTO M 31 specifications. Tie bars are deformed bars, and should be at least No. 5 bars (0.62 in. [16 mm]) spaced no more than 30 in. (760 mm) apart;
- Reinforcement in concrete overlays may be either deformed bars or welded wire fabric (WWF). Deformed reinforcing bars should conform to ASTM A 615 or AASHTO M 31, and WWF should conform to ASTM A 185 or AASHTO M 55. The amount of steel reinforcement should be determined based on the design conditions; and
- Joint sealant materials may be of three major types (see also ACI 504R): 1. Hot-poured rubberized materials conforming to ASTM D 6690, AASHTO M 301, or a governing state specification; 2. Silicone materials conforming to a governing state specification; or 3. Preformed compression seals conforming to ASTM D 2628, AASHTO M 220, or a governing state specification.

2.6—Concrete production, construction, and quality-control issues

2.6.1 Concrete production—Concrete production for overlays is no different than that for conventional pavement construction. ACI 304R provides guidance for materials handling, and requirements for measurements and batching equipment required to supply uniform, quality concrete to a paving job. The document also provides guidance for transporting concrete in revolving drum truck mixers and open-top truck bodies with and without agitators.

2.6.2 Concrete placement and finishing—The placement of a concrete overlay is generally no different from conventional concrete pavement placement. Specific recommendations for overlay placement include grade adjustments that leave the required thickness of the concrete overlay. The finishing of the overlay surface should follow the same practices used to finish any concrete pavement.

2.6.3 Texturing—Texturing of the finished concrete overlay surface is required to ensure adequate surface friction of the roadway. Initial texturing is often done with a burlap drag or turf drag, with the final texturing provided by tining. For roadways designed for vehicle speeds less than 50 mi/h (80 km/h), texturing the surface with a burlap drag, turf drag, or broom should be adequate, provided the corrugations produced are approximately 0.06 in. (1.5 mm) deep (ACPA 1999a).

For roadways designed for vehicle speeds higher than 50 mi/h (80 km/h), tining of the concrete pavement surface is required (ACPA 1999a). Tining provides macrotexture, which contributes to surface friction by tire deformation, and also channels surface water from between the pavement and the tire.

Tining has traditionally been conducted transversely and at uniform intervals, but some studies suggest that uniformly spaced transverse tining produces irritating pavement noise (Larson and Hibbs 1997; Kuemmel et al. 2000). Consequently, some agencies are experimenting with transverse tining that is randomly spaced and skewed to the centerline of the pavement, the pattern of which should be carefully designed and constructed to minimize discrete noise frequencies that are most objectionable to the human ear. In addition, some agencies are investigating the use of longitudinal tining, which produces lower noise levels than either uniformly or randomly spaced transverse tining. Tining should be performed as soon as the moisture sheen disappears from the concrete surface. Additional guidance on surface tining is found in reports by Kuemmel et al. (2000) and ACPA (2000b).

2.6.4 Curing—ACI 308R discusses curing concrete. Curing of the completed overlay may be accomplished using wet burlap, polyethylene, or liquid membrane-forming curing compounds that meet ASTM C 309 or AASHTO M 148. Proper curing is extremely important to the long-term performance of a concrete overlay.

While factors that have an effect on the curing of a concrete overlay are generally no different than for conventional concrete pavement, there are several characteristics of bonded overlays, UTW, and thin whitetopping that make curing particularly important. These include the presence of the existing pavement with its own thermal properties, the thinness of the overlay, and the lower w/cm and higher heat of hydration in bonded systems. With conventional concrete pavement, improper curing affects the rate of strength gain and can lead to drying shrinkage cracking and other surface defects; with bonded overlays, improper curing affects the bond strength and contraction stresses and can lead to overlay failure.
Challenges to proper curing occur at both the surface and the base of the overlay. If the temperature of the existing pavement is either very hot or very cold, it will impact the curing of the overlay. Similarly, if there is low ambient humidity or the ambient temperatures drop substantially after placement of the bonded concrete overlay, conditions are created that have an adverse effect on the curing of the pavement.

The application of a curing compound to the surface and exposed edges should be sufficient to control the rate of drying shrinkage in a bonded overlay. For bonded overlays, UTW, and thin whitetopping, a minimum application rate of 100 ft²/gal. (2.5 m²/L), which is about twice the typical manufacturer’s recommended rate, should be used (ACPA 1990a; Delatte et al. 1996a). Under harsh climatic conditions, the use of curing blankets may also be advisable. In some cases, temporarily halting paving when evaporation rates exceed ACI 305R recommendations is the best insurance against plastic shrinkage cracking. Delatte et al. (1996b) provide recommendations for curing under the harsh environmental conditions of southwestern Texas. Under such conditions, it is advisable to use a portable weather station to monitor ambient temperatures, wind speed, and relative humidity for determining rate of evaporation and potential for plastic shrinkage cracking (Delatte et al. 1998).

Because of the sensitivity of thin overlays to curing conditions, consideration may be given to the use of internal curing using a partial replacement of saturated lightweight fine aggregate. Background for internal curing and suggestions for mixture proportioning are given in Bentz et al. (2005) and Lam (2005).

2.6.5 Quality control—As with conventional concrete pavement construction, the quality-control program is an important element of the construction process. The program should be written and should include procedures that ensure all materials comply with job specifications, and that concrete production and construction procedures are consistent with good practice and relevant specifications. Information on programs can be found in ACI 311.4R, 311.5, and 121R. Personnel inspecting, testing, or finishing concrete should be certified, either under the ACI Certification Program or the program required by the state highway agency. Information on the ACI program can be found at www.concrete.org/certification.

CHAPTER 3—SELECTION OF CONCRETE OVERLAY ALTERNATIVES

3.1—Introduction

The selection of a particular type of concrete overlay as a possible rehabilitation alternative for an existing pavement is a subset of the overall pavement rehabilitation selection process. The basic principles of that overall pavement rehabilitation selection process are summarized in several documents, including the 1993 “Guide for Design of Pavement Structures” (AASHTO 1993), “Pavement Rehabilitation Strategy Selection” (ACPA 1993), and the reference manuals for two National Highway Institute (NHI) training courses (Groog et al. 2001; Hoerner et al. 2001). With the implied goal of optimizing pavement rehabilitation, the process involves first identifying rehabilitation alternatives that are technically feasible, and then evaluating the candidate alternatives in terms of cost and performance benefits to identify the most appropriate option.

Conceptually, a general relationship exists between the existing pavement condition and the required type of rehabilitation, as shown in Fig. 3.1. That is, as pavements reach a more advanced state of deterioration, more substantial rehabilitation measures are required.

The selection process, however, is complicated by the need to consider a variety of factors, many of which are difficult to quantify and evaluate in comparable terms. Examples of such factors include user costs, lane-closure requirements, traffic-control considerations, desired performance life, duration of construction, and local experience with the rehabilitation alternative. The inability to reliably predict the performance of rehabilitated pavements is also a significant shortcoming in the process. Concrete pavement rehabilitation selection has been the topic of several research projects, including NCHRP Web Document 45 and NCHRP Research Results Digest 272, and an FHWA-sponsored research project that is part of the Concrete Pavement Technology Program (Task 54 (99)) entitled “Repair and Rehabilitation of Concrete Pavements.” It can be found at http://www.fhwa.dot.gov/pavement/concrete/sr04apb2.cfm.

3.2—Effectiveness of different types of concrete overlays

In practice, candidate alternatives for pavement rehabilitation considerations are not limited to concrete overlays; therefore, where appropriate, hot-mix asphalt counterparts to concrete overlays are also mentioned. Table 3.1 provides a summary of the advantages and disadvantages of different types of overlays.

3.2.1 Bonded concrete overlays—Bonded overlays are appropriate for concrete pavements that are in good condition but are in need of structural enhancement. Bonded overlays can also be used to address various types of functional deficiencies, including the following:

- Poor surface friction;
- Surface roughness (other than faulting);
- Surface rutting caused by studded tires; and
- Excessive noise levels.
Studies on the field performance of bonded concrete overlays have shown mixed results (Hutchinson 1982; Voigt et al. 1989; Peshkin and Mueller 1990; McGhee 1994). Although many projects have provided good long-term performance, several failed within a few years after construction. These failures were often characterized by reflective cracking and corner breaks (in areas where bond was lost). Most of these failures, however, were attributed to the application of the bonded overlay to a pavement that was extensively cracked (McGhee 1994). Others are attributed to inadequate or ineffective preoverlay repair (Peshkin and Mueller 1990). The performance of those projects is summarized elsewhere (Hutchinson 1982; McGhee 1994). Nevertheless, where used in an appropriate application, bonded concrete overlays have provided good performance. Details of case studies are provided by Smith et al. (2002).

When considering a bonded concrete overlay, it is imperative that the existing structural capacity of the underlying pavement not already be compromised. Where structural-related distresses are present, such as pumping, faulting, midpanel cracks, or corner breaks, the load-carrying capabilities of the underlying pavement are already compromised, and a bonded concrete overlay is not an appropriate rehabilitation technique. Furthermore, the presence of D-cracking or other materials-related distresses in the underlying concrete suggest conditions where the effectiveness of a bonded overlay may be limited.

Structurally, hot-mix asphalt overlays (without slab fracturing) are similar to bonded concrete overlays, so if a 10- to 15-year service life is acceptable, then a hot-mix asphalt overlay could be used to obtain similar performance as a bonded concrete overlay, although with a shorter service life. Concrete pavements overlaid with hot-mix asphalt are subjected to much lower temperature gradients (Nishizawa et al. 2000). Thus, while hot-mix asphalt overlays do not provide the same level of reduction in load stresses as bonded concrete overlays, a reduction in combined stresses can be achieved with a moderate thickness hot-mix asphalt overlay because of the lower thermal curling stresses.

### Table 3.1—Advantages and disadvantages of different types of pavement overlays

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Applicability</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical life*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete overlays</strong></td>
<td></td>
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<tr>
<td>Bonded</td>
<td>Concrete pavement in relatively good condition with no materials-related distress</td>
<td>Significant increase in structural capacity can be achieved with a relatively thin (3 to 6 in. [75 to 100 mm]) overlay</td>
<td>For pavements in good condition only</td>
<td>15 to 25 years</td>
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<tr>
<td></td>
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<td></td>
<td>Requires extensive preoverlay repairs.</td>
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<td></td>
<td>Working cracks on existing pavement will reflect through</td>
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<td></td>
<td></td>
<td></td>
<td>Bond is essential to good performance</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Longer duration of construction than hot-mix asphalt overlays</td>
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<td></td>
<td></td>
<td></td>
<td>High initial cost</td>
<td></td>
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<tr>
<td>Unbonded</td>
<td>All concrete pavements</td>
<td>Relatively insensitive to condition of the underlying pavement—can be applied to concrete pavements in poor condition</td>
<td>Vertical clearances can be a problem</td>
<td>20 to 30 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Requires minimal preoverlay repairs</td>
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<td></td>
<td></td>
<td></td>
<td>High reliability</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Longer duration of construction than hot-mix asphalt overlays</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>High initial cost</td>
<td></td>
</tr>
<tr>
<td>Whitetopping</td>
<td>All hot-mix asphalt pavements</td>
<td>Longer design life than hot-mix asphalt</td>
<td>Vertical clearances can be a problem</td>
<td>20 to 30 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Can be applied on badly deteriorated hot-mix asphalt pavements</td>
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<td></td>
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<td></td>
<td>Eliminates rutting and shoving problems</td>
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<td>High reliability</td>
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<td></td>
<td>Longer duration of construction than hot-mix asphalt overlays</td>
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<td></td>
<td>High initial cost</td>
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<td></td>
<td></td>
<td></td>
<td>Debonding can lead to premature failure</td>
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<td>Requires a thicker hot-mix asphalt pavement with adequate structural capacity</td>
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<td></td>
<td>Longer duration of construction than hot-mix asphalt overlays</td>
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<td></td>
<td></td>
<td></td>
<td>High initial cost</td>
<td></td>
</tr>
<tr>
<td>UTW</td>
<td>Hot-mix asphalt pavements in fair to good condition</td>
<td>Longer design life than hot-mix asphalt</td>
<td>Debonding can lead to premature failure</td>
<td>5 to 15 years (estimated)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Eliminates rutting and shoving problems</td>
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<td></td>
<td></td>
<td></td>
<td>High reliability</td>
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<td></td>
<td></td>
<td></td>
<td>Longer duration of construction than hot-mix asphalt overlays</td>
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<td>High initial cost</td>
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<td><strong>Hot-mix asphalt overlays</strong></td>
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<td></td>
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<tr>
<td>Hot-mix asphalt overlays without slab fracturing</td>
<td>Concrete pavement in fair to good condition</td>
<td>East to construct</td>
<td>Susceptible to reflection cracking</td>
<td>8 to 15 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Short duration of construction</td>
<td>Existing structural distresses should be repaired full depth to avoid reflection cracking</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Low cost</td>
<td>May accelerate materials-related distress</td>
<td></td>
</tr>
<tr>
<td>Hot-mix asphalt overlays with slab fracturing</td>
<td>All badly deteriorated concrete pavements</td>
<td>Shorter duration of construction than concrete overlays</td>
<td>Breaking or cracking and seating may not always prevent reflection cracking</td>
<td>8 to 25 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High reliability for preventing reflective cracking (rubbleization)</td>
<td>A relatively thick overlay is needed after rubblization to obtain desirable performance</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Vertical clearances can be a problem</td>
<td></td>
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</tbody>
</table>

*Life estimates based on data provided by Hall et al. (2001).
preoverlay repairs, the existing pavement may also be fractured before overlaying, which may be appropriate if the existing pavement is severely deteriorated structurally or if it is exhibiting materials-related problems.

An alternative to an unbonded overlay is the placement of a hot-mix asphalt overlay, with or without slab fracturing. These can be placed very quickly and at a lower initial cost than unbonded concrete overlays. For severely deteriorated concrete pavements or concrete pavements with material-related deterioration, slab fracturing may be the most economical and reliable approach to preparing the existing pavement for the overlay. On the other hand, the main advantage of the unbonded concrete overlay option over the hot-mix asphalt overlay option is the longer expected service life. Other benefits include lower maintenance costs, better reflectivity for improved visibility, and higher skid resistance.

### 3.2.3 Whitetopping overlays

Whitetopping is an effective method for rehabilitating deteriorated hot-mix asphalt pavements that exhibit severe structural deterioration, such as rutting, shoving, and alligator cracking. Little preoverlay repair is required before placing a whitetopping overlay, although some milling may be needed if significant rutting exists or if other profile corrections are needed (ACP 1991b, 1998). Structurally, whitetopping overlays are similar to conventional concrete pavements constructed on an asphalt-treated base. Whitetopping overlays have been successfully constructed with JPCP, JRPC, and CRCP designs, but JPCP designs are most common. The majority of the whitetopping projects have provided good to excellent performance (Lokken 1981; Hutchinson 1982; McGhee 1994; ACP 1998).

### 3.2.4 UTW overlays

UTW overlays are best suited to hot-mix asphalt pavements on local roads, intersections, or parking lots that exhibit severe rutting, shoving, and pothole problems. Because the underlying hot-mix asphalt pavement is an integral part of the structural system for UTW overlays, a minimum hot-mix asphalt thickness of 3 in. (75 mm) (after milling) is required for UTW projects (Grogg et al. 2001), although some suggest a minimum hot-mix asphalt thickness of 6 in. (150 mm) (Silfwerbrand 1997). Proper preparation of the existing hot-mix asphalt pavement is also essential to ensure good performance of UTW overlays. This includes repair of any failed or severely deteriorated areas to provide adequate (and uniform) load-carrying capacity and milling of the hot-mix asphalt surface to promote good bonding. Although long-term performance data are limited, the short-term performance of UTW projects has generally been good (Cole 1997).

### 3.3—Selection process

Although some aspects of pavement rehabilitation selection are well defined, the selection process is complicated by the need to consider numerous factors that are difficult to quantify and evaluate in comparable terms. The process involves the following steps:

- **Phase 1: Problem definition**—In this step, the condition of the pavement is established, the needs are determined, and any project constraints identified;
- **Phase 2: Potential problem solutions**—This step sorts through all available solutions and develops a short list of feasible solutions that address the needs and constraints of the project; and
- **Phase 3: Select preferred solutions**—This step considers both monetary and nonmonetary factors to select the alternative deemed most appropriate for design conditions and constraints.

In general, the pavement-related aspects of this process are well defined, and the guidelines provided in numerous references can be used to identify technically feasible and preferable rehabilitation alternatives.

The selection process is much simpler if only concrete overlay alternatives are considered, but there is no practical value in limiting rehabilitation choices in that way. The choice among concrete overlays is often clearly defined by the engineering criteria. Where more than one type of concrete overlay is feasible, the selection may be based on life-cycle costing, because the impact of construction, which affects most of the nonmonetary factors, is similar for all concrete overlays. When other rehabilitation alternatives, such as hot-mix asphalt overlay alternatives, concrete pavement restoration alternatives, and reconstruction, are also considered, user costs and nonmonetary factors become more relevant. The decision matrix shown in Table 3.1 can be a useful tool for identifying the alternative that best satisfies multiple selection criteria. One limitation of this approach is that it is difficult to rate different alternatives so that the relative merits of each alternative are properly represented in the rating for many of the factors.

Although most state highway agencies regard user cost and nonmonetary factors as very important decision factors in rehabilitation selection, there are no generally accepted means of combining these factors. For the most part, an informal process is used, although systematic procedures for rehabilitation selection are currently being developed under ongoing research projects.

### CHAPTER 4—BONDED CONCRETE OVERLAYS

#### 4.1—Introduction

A bonded overlay increases the overall structural capacity of the pavement, but that structural benefit only occurs when the overlay and the underlying concrete behave monolithically. Thus, effective bond between the concrete overlay and the existing pavement is critical to the performance of these overlays. When a bonded overlay is properly constructed and the application is appropriate, its expected advantages are that it lasts longer than conventional hot-mix asphalt overlays, and it provides a higher level of serviceability over its service life.

Bonded concrete overlays have been used as a pavement rehabilitation technique for almost 90 years (Hutchinson 1982; Delatte and Laird 1999). A number of highway agencies have substantial experience with bonded overlays, both in the U.S. and internationally. Among some of the agencies in the U.S. that have constructed bonded concrete overlays are Texas, Iowa, Pennsylvania, Louisiana, Virginia, Illinois, and California. These experiences cover a wide range of overlay
designs placed over a variety of pavement types and conditions. Sprinkel (2000) documents the performance of bonded concrete overlays that were constructed under the 1991 ISTEA legislation.

4.2—Design

4.2.1 General design considerations—As previously mentioned, a bonded concrete overlay is an appropriate rehabilitation strategy when the structural capacity of a pavement needs to be increased. This need is identified by an anticipated increase in traffic rather than by signs of pavement deterioration, which are the more common triggers of pavement rehabilitation. Even after a bonded overlay is determined to be feasible, however, it is important to evaluate the pavement to confirm that it is a good candidate for a bonded overlay. Recommended evaluation steps include the following:

• Evaluation of existing pavement condition—Refer to Section 4.2.2; and
• Traffic evaluation—Bonded concrete overlays are a good method for improving the load-carrying capacity of an existing concrete pavement. Because a properly designed and constructed bonded overlay can provide many years of performance, care should be taken to develop meaningful projections of future traffic as an input to the design process.

Bonded concrete overlays are constructed within the same general range of thicknesses as hot-mix asphalt overlays. As such, the same construction considerations regarding overhead clearances, shoulder drop-offs, and guardrails that apply to the use of hot-mix asphalt overlays also apply to the use of bonded concrete overlays.

Most bonded concrete overlays are JPCP designs, with transverse and longitudinal joints matching those in the underlying pavement. Some bonded JRCP overlays have been used on existing JPCP and JRCP; although presently, JRCP designs are rarely used. A few states, such as Texas and Virginia, have constructed bonded overlays on existing CRCP. In the case of overlays of JRCP and CRCP pavements, embedded steel is generally not used in the bonded overlay itself, as the overlay simply serves to increase the thickness and load-carrying capacity of the existing concrete pavement. For exceptionally thick overlays, reinforcing steel may be placed at the interface between the overlay and the prepared surface in order to keep the percentage of steel the same as for the original CRCP (Delatte et al. 1996b).

4.2.2 Pavement evaluation—As with the design of other types of overlays, an evaluation of the existing pavement provides important information used to determine whether a bonded overlay is the appropriate method of structural improvement. A comprehensive evaluation typically consists of a visual distress survey, deflection testing using the falling weight deflectometer, and coring. The visual distress survey is the first step in determining the suitability of the pavement for a bonded overlay. The visual survey should be carried out using the FHWA Distress Identification Manual.

The primary purpose is to determine if structural deterioration is present to the extent that it will impair the performance of the overlay. Examples of distresses that indicate structural deterioration include:

• Deteriorated transverse cracking;
• Corner breaks;
• Pumping;
• Faulting; and
• Punchouts (CRCP). Where any of these are present, their severity and extent should be considered to determine whether a bonded overlay is appropriate. If not widespread, full-depth repairs before placement of the overlay will help to minimize their effect on future performance. Where these distresses are widespread or too severe, a bonded overlay will not perform well.

If material-related distress, such as D-cracking or reactive aggregate, is present, an analysis of the cores from the existing pavement can help to identify the nature and extent of the problem. D-cracking, for example, typically begins at the bottom of the pavement, so that by the time it is visible on the surface much of the pavement’s integrity is compromised. Pavements with material-related distress are not good candidates for bonded overlays.

The existing pavement’s structural capacity is a key consideration in selection of the proper type of overlay, and the best method to determine structural capacity is by deflection testing with a falling-weight deflectometer. The information that can be obtained from falling-weight deflectometer testing results includes the following:

• Back-calculated subgrade k-value and concrete modulus;
• Subgrade variability;
• Load transfer efficiency; and
• Presence of voids under joints and cracks.

The back-calculation can be accomplished using the procedure provided in the AASHTO “Guide for Design of Pavement Structures” (AASHTO 1993), the “Supplement to the AASHTO Guide for Design of Pavement Structures” (AASHTO 1998), or any other established procedures. More detailed information on concrete pavement back-calculation is provided by Hall (1992). Recommended void detection procedures are described by Covetetti and Darter (1985).

4.2.3 Thickness design—The typical thickness of a bonded concrete overlay is between 2 and 4 in. (50 and 100 mm). This range is defined at the low end by the minimum thickness that can be placed by slip form paving equipment. At the high end, economic considerations and practical concerns, such as clearances and matching grades, control the maximum overlay thickness.

4.2.3.1 AASHTO overlay design procedure—One widely used bonded overlay design procedure is described in the AASHTO “Guide for Design of Pavement Structures” (1993). This methodology is based on the structural deficiency approach, in which the required structural capacity of a new overlay (SCOL) is equal to the difference between the structural capacity of a new pavement (SCf) needed to carry the projected (future) traffic and the effective structural capacity of the existing pavement (SCeff). This concept is illustrated in Fig. 4.1.
The structural capacity for concrete overlays is represented by the slab thickness. For bonded concrete overlays, the required overlay thickness may be computed as

\[ D_{OL} = D_f - D_{eff} \]  

(4-1)

where

\[ D_{OL} = \text{thickness of the bonded concrete overlay, in. (mm)}; \]
\[ D_f = \text{required thickness of a new concrete pavement for the future traffic loadings, in. (mm);} \] and
\[ D_{eff} = \text{effective thickness of the existing slab, in. (mm)}. \]

The thickness required to carry future loadings \( D_f \) can be determined using the AASHTO design procedure for new concrete pavements or any new concrete pavement thickness design procedure. In the AASHTO procedure, the effective thickness of the existing slab \( D_{eff} \) can be calculated from one of two methods:

1. **Condition survey method**—In this method, the actual thickness of the existing concrete pavement is reduced based on observed distress conditions; the more distress, the less the effective thickness. The effective thickness is computed as

\[ D_{eff} = D \times F_{jc} \times F_{dur} \times F_{fat} \]  

(4-2)

where

\[ D = \text{actual thickness of the existing slab, in. (mm)}; \]
\[ F_{jc} = \text{joint condition adjustment factor}; \]
\[ F_{dur} = \text{durability adjustment factor}; \] and
\[ F_{fat} = \text{fatigue damage adjustment factor}. \]

2. **Remaining life method**—In this method, the amount of traffic that the existing pavement has carried to date is compared with its design traffic, which provides an estimate of its remaining life. By knowing the remaining life, a chart in the AASHTO design guide can be used to determine a condition factor \( CF \) that is used to estimate the effective slab thickness as follows

\[ D_{eff} = CF \times D \]  

(4-3)

where

\[ CF = \text{condition factor estimated based on remaining life}. \]

**4.2.3.2 Portland Cement Association (PCA) overlay design procedure**—The PCA also has a design procedure for bonded concrete overlays based on a structural equivalency approach (Tayabji and Okamoto 1985). In this approach, the overlay thickness is determined so that critical stresses in the monolithic structure are equal to or less than the critical stresses in a new concrete pavement. Design charts for three categories of flexural strength of the existing concrete pavement that produce minimum and maximum overlay thicknesses of 2 and 5 in. (50 and 125 mm), respectively, are available.

**4.2.3.3 U.S. Army Corps of Engineers (USACE) and Federal Aviation Administration (FAA) overlay design procedures**—USACE design procedures are provided in Unified Facility Criteria (UFC) 3-260-02. USACE design programs are available at http://www.pcase.com. FAA design procedures are provided in the FAA “Airport Pavement Design.” FAA design programs are available at http://www1.faa.gov/arp/engineering/software.cfm.

**4.2.4 Joint design**—Because the performance of a bonded overlay depends on creating a monolithic pavement structure, the joints in the overlay should match the joints in the underlying pavement. Matched joints help to ensure that the two layers of the pavement structure are able to move together, helping to maintain bond between them. Matched joints also help to prevent reflection cracking. Because of the importance of matched joints, not only should the location of the joint be matched, but also the joint width and type; that is, if there is an expansion joint in the underlying pavement, it should be recreated in the overlay. Dowels or other load-transfer devices are not used in conventional thin bonded overlays.

**4.2.5 Concrete mixture proportioning**—Achieving and maintaining adequate bond between the overlay and the existing pavement is an important factor for overlay performance. The mixture proportioning of the overlay plays a role in this because it affects how the overlay will perform as it undergoes drying shrinkage and thermal movement. Delatte et al. (1998) recommend that the mixture be proportioned for rapid strength gain, minimum thermal expansion and contraction, and minimum shrinkage. Conventional mixtures have been used successfully and are acceptable for most applications. High-early-strength mixtures have also been used successfully, and should be considered where the pavement must be reopened to traffic on an accelerated schedule. In either case, a water-reducing admixture is commonly used to reduce the w/cm (ACPA 1990a). Components of the mixture that should be carefully considered include:

- **w/cm**—The higher the w/cm, the lower the strength of the concrete at any given time;
- **Paste content**—The higher the paste content, the higher the potential for drying shrinkage as free water evaporates; therefore, the concrete mixture should be proportioned with the lowest practical w/cm and maximum size and volume of coarse aggregate;
- **Portland cement content**—High cement contents result in high temperatures caused by heat generated in the
hydration process, which affect the rate of set. If rapid setting and high temperatures are not anticipated and controlled, they can be a problem for the contractor and may cause early-age cracking when the concrete cools under restrained conditions;

- **Thermal properties**—The differences in the coefficient of thermal expansion between the concrete overlay and the subbase determine how much stress occurs at the bonded interface during thermal cycling of the pavement. To minimize the stress, the overlay concrete and the existing concrete should have similar thermal properties. Because the coefficient of thermal expansion (CTE) of the aggregate is the primary determinant of the concrete CTE, the overlay concrete should use aggregates with thermal characteristics similar to the existing concrete; and

- **Aggregate moisture condition**—Loss of moisture from the concrete can contribute to early-age shrinkage cracking and debonding of the concrete overlay. Pore space in the aggregate should be fully saturated before batching, otherwise the aggregate will tend to pull water from the mixture at early ages, increasing the possibility of shrinkage, which can lead to debonding.

Examples of bonded concrete overlay mixture proportions are provided in Smith et al. (2002). As described in Chapter 2, fibers have also been used in bonded overlay mixtures, but they are not a required constituent. The potential benefits of using fibers are addressed in ACI 544.1R as well as PCA documents (1991, 2002).

4.2.6 **Drainage**—The bonded overlay evaluation and design phases provide an opportunity to evaluate existing pavement drainage characteristics and to upgrade them if necessary. Pavement performance indicators that signal a need to improve drainage capabilities include pumping, faulting, and corner breaks. The pavement cross slope should also be evaluated; current recommendations suggest a minimum cross slope of 1.5%, and this should be carried through to the bonded overlay.

If it is determined that the existing pavement’s drainage characteristics are deficient, the feasibility of retrofitting edge drains should be considered. Several National Highway Institute training courses (ERES 1999b; Hoerner et al. 2001) provide detailed information on the evaluation and design of drainage facilities in pavement rehabilitation.

4.3—**Construction**

4.3.1 **Preoverlay repair**—Although a bonded overlay is most appropriate for pavements in good structural condition, some degree of preoverlay repair may be required. An important consideration is whether movement in the underlying pavement, either due to environmental conditions or to applied loads, will cause movement in the overlay. Any movement in the overlay that does not occur at matched joints (or cracks) will contribute to debonding and the subsequent deterioration of the overlay.

Appropriate preoverlay repairs include:

- Full-depth repair of medium- and high-severity transverse and longitudinal cracking, corner breaks, and punchouts (CRCP);
- Partial-depth repair of joint spalling;
- Slab stabilization to fill voids and prevent future pumping and loss of support; and
- Load transfer restoration across working cracks or nondoweled joints.

Hoerner et al. (2001) provide more detailed information on these repair activities. Note that if any deterioration, such as joint spalling, is due to a materials-related distress, a bonded overlay is probably not an appropriate rehabilitation strategy. A life-cycle cost analysis is recommended to evaluate whether the cost of extensive repairs, in combination with the cost of the bonded concrete overlay, suggest the need to consider alternatives such as unbonded concrete overlays.

4.3.2 **Surface preparation**—After selection of the proper overlay type, surface preparation probably has the greatest impact on the long-term performance of bonded overlays. The objective is to remove contaminants, loose concrete, paint, and other materials that could adversely affect the bonding of the overlay, and to provide a coarse macrotexture that promotes the mechanical bond between the old and the new pavement.

Over the years, many different surface preparation procedures have been used, including sandblasting, shotblasting, waterblasting, scabbling, milling, and acid etching. Today, the most commonly used (and most effective) surface preparation procedure is shotblasting, which is often followed by sandblasting and air blasting immediately before placement of the overlay. Shotblasting and air blasting equipment and a prepared surface are illustrated in Fig. 4.2. Alternatively, waterblasting is also reported to provide a suitable surface, but the surface should be allowed to dry before the placement of the overlay (Delatte and Laird 1999).

The surface preparation technique should not be so aggressive that it damages the underlying pavement. Warner et al. (1998) note that commonly used preparation techniques, such as shotblasting and waterblasting, cause little bruising of the existing surface, while more aggressive preparation techniques (scabblers and drum-type carbide pick mills, for example) strike the pavement with great force and can create a weak layer in the existing pavement immediately below the bond interface. ACI 546R provides additional guidance on concrete removal and surface preparation techniques.

The ability of a surface preparation method to create the desired surface texture can be assessed by physical measurement. The sand patch test (ASTM E 965) is one widely-used surface texture measurement procedure. ASTM C 1583 is a method for evaluating the strength of prepared surfaces.

Another surface preparation issue involves whether or not to prewet the surface. Some believe the surface should be completely dry, whereas others believe that prewetting of the existing surface (to a saturated surface dry [SSD] condition) can be extremely beneficial because it can help control the moisture demand from the bonded concrete overlay. If too much moisture is absorbed by the existing pavement from the plastic concrete, shrinkage will occur, and debonding is likely to follow. Regardless of whether the surface is prewetted, Wells et al. (1999) recommend that some degree of surface preparation be required to achieve bond.
Another debate in the placement of bonded concrete overlays involves whether to use a grout or epoxy bonding agent at the interface between the substrate concrete and the concrete overlay. While these materials can be used to promote bond, they also have the potential to act as debonding layers if their placement is not carefully controlled. The consensus is that with the proper surface preparation technique, a bonding agent is not required (ACPA 1990a; Whitney et al. 1992; Wells et al. 1999; Sprinkel 2000). In fact, in a study of bonded concrete overlays constructed under the 1991 ISTEA legislation, Sprinkel (2000) concluded that shotblasting followed by an SSD surface and no grout provides very good bond strength. In addition, Wells et al. (1999) showed that without sufficient surface preparation, the use of a bonding agent alone was not enough to promote sufficient bond; it was also demonstrated that bonding agents with higher strengths than conventional cement slurry were not likely to lead to higher bonding strengths.

If used, a typical mixture for a bonding agent consists of 1726 lb (783 kg) of cement to 853 lb (387 kg) of water, with a maximum w/c of 0.62 (ACPA 1990a). During placement, it is important that the bonding agent be placed immediately in front of the paver with a separation of no more than 10 ft (3 m) to prevent it from drying before the overlay is placed (ACPA 1990a).

The bonding of the concrete pavement overlay is also significantly affected by the prevailing climatic conditions at the time of construction, such as ambient temperature, humidity, and wind speed (McCullough and Rasmussen 1999a). If significant stresses develop during the first 72 hours following concrete placement, debonding of the overlay from the underlying pavement may occur.

As with many of the construction steps, the ultimate objective of surface preparation is to achieve the desired bond strength between the two concrete layers of the pavement structure. The literature teems with references to bond strength and the steps used to achieve it and measure it. Refer to Warner et al. (1998) for an example of a summary of procedures to measure bond strength. Common guidance on the required bond has suggested a bond (Iowa type shear) strength of 200 psi (1.4 MPa) between the two concrete layers is sufficient (ACPA 1990a).

Placement, finishing, and texturing—The placement of a bonded concrete overlay is generally no different from that of conventional concrete. Specific recommendations for bonded overlay placement include the following (ACPA 1990a):

- Grade adjustments should be made to ensure the required thickness of the bonded concrete overlay; and
- Normally, vehicles should not be allowed on the prepared surface after the surface preparation is completed. If it is absolutely necessary to have vehicles operating on the existing concrete, care should be taken that they do not drip oil or other contaminants that will affect the bond.

Texturing of the finished concrete pavement surface is required to ensure adequate surface friction of the roadway, as discussed in Section 2.6.3.

Curing—Proper curing is extremely important to the long-term performance of a bonded concrete overlay. While factors that have an effect on the curing of a bonded overlay are generally no different than for those of conventional concrete (Section 2.6.4), there are several characteristics of the bonded overlay that make curing particularly important. These include the presence of an existing concrete layer with its own thermal properties, and the relative thinness of the overlay. Therefore, applications of curing compound at twice the manufacturer’s recommended rate as discussed in Section 2.6.4 should be used.

Joint construction—Important factors in sawing joints in the bonded concrete overlays include location, timing, and depth. As noted previously, the location of transverse and longitudinal joints in the bonded concrete overlay should coincide closely with the joints in the underlying pavement. Experience suggests that even a small deviation will contribute to secondary cracking and spalling. Thus, it is necessary to lay out the joints in the underlying pavement accurately and carefully. A common technique is to locate the existing transverse joints with guide nails driven on either side of the pavement in the shoulder (and away from the track line of the paver). After the concrete overlay is placed, a chalk line is used to connect those guide nails across the new concrete overlay and then snapped to establish the transverse joint locations. Longitudinal joints, when uniform and consistent, can be easily located by measuring the horizontal offset from the edge of the existing pavement.

The timing of joint sawing for bonded overlays follows similar guidelines for any concrete pavement in that it should occur as soon as the surface can support the joint sawing equipment and the pavement can be sawed without spalling or raveling the joint. This is especially important for bonded overlays because of their thinness and the fact that if they crack before joints are formed, debonding is likely to occur. Depending on the mixture and the

Fig. 4.2—Shotblasting equipment and properly prepared surface.
prevailing climatic conditions, joint sawing operations generally occur within 4 to 12 hours after paving.

The depth of sawing for transverse joints in the bonded overlay must be the full specified depth of the bonded overlay plus 0.5 in. (12 mm) to account for variations in the actual depth of the bonded layer. The success of this critically important joint sawing procedure will obviously depend on the accurate location of the transverse joint, as described previously. A failure either to accurately locate the transverse joint in the bonded overlay over the transverse joint in the underlying pavement or to cut through the full depth of the bonded overlay and into the underlying joint can result in spalling and debonding at the transverse joint.

Guidance on the depth of joint sawing is given in Table 4.1. These guidelines are applicable to bonded overlays 6 in. (150 mm) or less in thickness. Most highway bonded concrete overlays are 4 in. (100 mm) thick or less, and most airport bonded overlays are 6 in. thick or less. For a bonded overlay thickness greater than 6 in. (150 mm), the depth of sawing should be determined on a case-by-case basis, the primary criterion to be considered being the need to keep compressive stress buildup (during hot summer days) at the uncut portion of the bonded overlay joint as small as possible, especially considering the expected ambient conditions at the time of construction and the thickness of the existing concrete pavement.

### CHAPTER 5—UNBONDED CONCRETE OVERLAYS

#### 5.1—Introduction

Unbonded concrete overlays are used most commonly to remedy structural deficiencies of existing concrete pavements. Compared with other types of overlays, the performance of unbonded overlays is relatively insensitive to the condition of the existing concrete pavement and, therefore, minimal preoverlay repairs are required in most cases. Consequently, candidate pavements for unbonded overlays are typically those with extensive deterioration, including those with material-related distresses such as D-cracking or reactive aggregate. Adequate consideration of the structural capacity of the existing pavement, however, is still necessary for the structural design of unbonded overlays, and preoverlay repairs of certain types of distresses are still needed to avoid localized failures. Other critical factors that affect the performance of unbonded overlays include the separator layer design, the joint spacing layout, and the load-transfer design.

An unbonded overlay should be adequately isolated from the underlying deterioration and allowed unrestricted horizontal movement; however, a certain amount of bonding or friction between the overlay and the separator layer and between the separator layer and the underlying pavement is also important to achieve good performance. Consequently, a more technically correct description of an unbonded overlay is a separated overlay.

#### 5.2—Design

##### 5.2.1 General design considerations

The design of unbonded overlays requires consideration of several factors. These are briefly described as follows:

- **Existing pavement type and condition**—In general, unbonded overlays are feasible when the existing pavement is extensively deteriorated; this includes pavements affected by severe material-related distress. Although pavement condition is less important for unbonded overlays than for bonded overlays, it is still important to ensure adequate and uniform support for the new overlay. Areas of significant pavement deterioration may have to be remedied;

- **Overlay type**—The selection of the overlay type depends largely on agency preference. By far the most common type of unbonded overlay is JPCP, although a significant number of CRCP overlays have been constructed. In general, the condition of the underlying pavement is more critical to the performance of unbonded CRCP overlays; CRCP overlays require more uniform support and an effective separator layer, such as 1 in. (25 mm) hot-mix asphalt, to ensure good performance;

- **Preoverlay repair**—Unbonded overlays do not require extensive preoverlay repairs, but repair of certain types of distresses, such as shattered slabs in JPCP and punchouts and deteriorated cracks in CRCP, are important to avoid localized failures. Additional discussion of preoverlay repairs is presented in Section 5.2.3; and

- **Separator layer design**—The design of the separator layer is critical to the performance of unbonded overlays. The separator layer should adequately isolate the overlay from underlying deterioration and provide sufficient friction to ensure proper formation of joints in JRCP and desirable crack spacing in CRCP. Additional information on separator layer design is presented in Section 5.2.5.

There are various site factors that can affect the feasibility of unbonded concrete overlays, including:

- Traffic control;
- Shoulders; and
- Overhead clearance.

In urban areas where traffic congestion is already a problem, management of detour traffic during construction can be a critical issue (TRB 1998). Lane closure requirements can be a key factor that determines the feasibility of unbonded overlays. For projects in congested areas, the use of fast-track paving techniques with unbonded overlays may be appropriate to minimize lane closure time. These techniques are discussed in ACI 325.11R.

In addition, the construction of an unbonded overlay requires the construction of new shoulders because of the increase in the elevation of the mainline pavement. The elevation change also means that interchange ramps have to be adjusted and guardrails may have to be raised, both of which affect the economic feasibility of unbonded overlays.

### Table 4.1—Recommended joint sawing depths for bonded concrete overlays

<table>
<thead>
<tr>
<th>Joint type</th>
<th>Depth of cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse contraction</td>
<td>Nominal thickness + 0.5 in. (12 mm)</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>1/2 nominal thickness</td>
</tr>
<tr>
<td>Expansion</td>
<td>Nominal thickness + 0.5 in. (12 mm)</td>
</tr>
</tbody>
</table>
Overhead clearances also affect the feasibility of unbonded overlays. Because unbonded overlays add significant thickness to a pavement’s overall cross section, short sections of reconstruction may be required at overhead structures, such as bridge overpasses, to ensure that adequate vertical clearance is provided. Raising the structure is another alternative. Both of these options, however, add complexity, time, and cost to pavement rehabilitation projects, which makes unbonded overlays less favorable on projects that include many overhead structures.

5.2.2 Pavement evaluation—As with other types of overlays, a thorough evaluation of the existing pavement is also important in the unbonded overlay design process. Pavement evaluation techniques typically include a visual distress survey, deflection testing using a falling weight deflectometer, and coring. If material-related distress, such as D-cracking or reactive aggregate problems, is present, laboratory testing of the core may also be needed to verify the nature of material-related distress and to assist in avoiding similar problems in the new overlay.

The existing pavement condition is a key input to thickness design in all design procedures. In both the AASHTO (1993) and PCA (Tayabji and Okamoto 1985) overlay design procedures, the structural value of the existing pavement is determined based on visual distress survey results. The condition survey is also important for identifying the areas that should be repaired before overlaying and for identifying material-related distress or drainage problems that require special consideration. The preferred method of characterizing the structural condition of the existing pavement for rehabilitation design is through falling weight deflectometer testing as discussed in Section 4.2.2.

5.2.3 Preoverlay repair—Unbonded concrete overlays generally require minimal preoverlay repairs. Only the distresses that cause a major loss of structural integrity require repair. Those distresses, and their recommended method of repair, are as follows (Hutchinson 1982; ACPA 1990b; ERES 1999a):

- Shattered slabs should be replaced;
- Punchouts in CRCP should be full-depth repaired;
- High-severity transverse cracks with ruptured steel on CRCP should be full-depth repaired;
- Unstable slabs or pieces of slabs with large deflections or pumping should be full-depth repaired or underslaved;
- High-severity spalling at existing pavement joints or cracks should be filled and compacted with hot-mix asphalt; and
- Settlements, if significant, should be leveled up with hot-mix asphalt.

Faulting is generally not a problem when a thick separator layer (1 in. [25 mm] or more of hot-mix asphalt) is used. Diamond grinding or milling, however, is recommended for faulting higher than 0.25 in. (6 mm). Alternatively, a thicker separator layer (2 in. [50 mm] hot-mix asphalt) may be used when faulting exceeds 0.25 in. (6 mm).

If construction of an unbonded CRCP overlay is contemplated, more attention should be paid to preoverlay repair activities to ensure that the existing distresses do not reflect through the overlay (ERES 1999a). Depending on the condition of the existing pavement, a thicker separator layer, a higher steel content, or a thicker overlay may be used to address concerns for reflection cracking.

As an alternative to preoverlay repairs, the existing pavement may be fractured to provide a more uniform support under the overlay. Some European countries have used this technique with excellent results (FHWA 1993). In Germany, the standard practice for unbonded overlay construction is to crack and seat the existing concrete pavement, place a 4 in. (100 mm) lean-concrete separator layer, and place the concrete overlay (FHWA 1993). Notches are cut into the lean-concrete separator layer (matched to the joints in the overlay) to prevent random cracking. For pavements with severe material-related distress, slab fracturing may be particularly applicable because the continued progression of material-related distress in the original pavement can cause premature deterioration of thinner (7 in. [175 mm]) unbonded overlays (ERES 1999a).

5.2.4 Thickness design—The thickness of unbonded overlays on major highways has ranged from approximately 7 in. (175 mm) to more than 10 in. (250 mm). Thicknesses can be determined using several design methods, several of which are described in Sections 5.2.4.1 through 5.2.4.3. It is important, however, to recognize that thickness alone does not ensure adequate performance, and other key factors, such as separator layer design and joint design, should be considered.

5.2.4.1 AASHTO overlay design procedure—The most common procedure for the design of unbonded concrete overlays is the methodology used in the AASHTO “Guide for Design of Pavement Structures” (1993). This methodology is based on the structural deficiency approach, in which the required structural capacity of a new overlay $SC_{OL}$ is equal to the difference between the structural capacity of a new pavement $SC_T$ needed to carry the projected traffic and the effective structural capacity of the existing pavement $SC_{eff}$. This concept was previously illustrated in Fig. 4.1.

The structural capacity for concrete overlays is represented by the slab thickness. For unbonded concrete overlays, the required overlay thickness may be computed as

$$D_{OL} = \sqrt{\frac{D_j^2 - D_{eff}^2}{SC_{eff}}}$$

The origin of Eq. (5-1) is believed to date back to the analysis of the performance data at the Bates Road Test (Older 1924), and it remains the most widely used procedure for the structural design of unbonded overlays (Hall et al. 1993).

The thickness required to carry future loadings $D_j$ can be determined using the AASHTO design procedure for new concrete pavements or any new thickness design procedure. In the AASHTO procedure, the effective thickness of the existing slab $D_{eff}$ can be calculated from one of two methods:

- **Condition survey method**—In this method, the actual thickness of the existing pavement is reduced based on observed distress conditions; the more distress, the less the effective thickness. The effective thickness is computed as
These procedures are the same as those cited in Section 4.2.3.3.

Unlike the bonded overlay design equation, there are no adjustment factors for durability or fatigue damage because of their minimal effect on the performance of the unbonded overlay (AASHTO 1993). A chart for determining $F_{jcu}$ is provided in the AASHTO “Guide for Design of Pavement Structures” (1993); and

- **Remaining life method**—In this method, the amount of traffic that the existing pavement has carried to date is compared with its design traffic, which provides an estimate of its remaining life. This method was described in Section 4.2.3.1. The designer should recognize that the effective thickness determined using this method does not reflect the benefit of any preoverlay repair.

5.2.4.2 **PCA overlay design procedure**—PCA has a design procedure for unbonded overlays that uses a structural equivalence approach (Tayabji and Okamoto 1985), as described in Section 4.2.3.3. Three different design charts are available to determine the required unbonded overlay thickness for existing pavements in good, fair, and poor condition. The PCA design procedure is consistent with mechanistic design principles, and accurate results can be obtained if the stress equivalencies are established considering all stress components (that is, both load and curling/warping stresses). Curling and warping stresses, however, are not considered in the procedure.

5.2.4.3 **USACE and FAA overlay design procedures**—These procedures are the same as those cited in Section 4.2.3.3.

5.2.4.4 **Discussion on current unbonded overlay design procedures**—Current unbonded overlay design procedures have significant limitations. Some of the major flaws in the existing thickness design procedures include:

- **Lack of consideration of layer interaction**—The structural contribution of the separator layer and the effects of friction or bonding between the overlay and the separator layer and between the separator layer and the underlying concrete pavement are ignored;

- **Excessive credit given to existing pavement**—Design procedures that are based on structural deficiency (AASHTO 1993) tend to produce unconservative results when the existing pavement is relatively thick; and

- **Lack of consideration of curling and warping stresses**—The effects of curling and warping are even more critical for unbonded overlays than for new pavements because of the very stiff support provided by the underlying pavement; however, existing design procedures do not consider the effects of curling and warping. The main result of this deficiency is that the effects of joint spacing on critical stresses are not reflected in the thickness design. For unbonded JPCP overlays with long joint spacings, such as higher than 15 ft (4.6 m), the lack of consideration of curling and warping stresses is a critical deficiency that often leads to unconservative overlay thicknesses.

These deficiencies offset each other to a certain extent for overlays that have a relatively thick (1 in. [25 mm] or more) hot-mix asphalt separator layer as long as the joint spacing is not excessive (higher than 15 ft [4.6 m]). For example, ignoring the structural contribution of the hot-mix asphalt separator layer and the layer interactions leads to conservative overlay thicknesses; however, excessive credit given to the existing pavement and lack of consideration of curling and warping stresses tend to produce unconservative overlay thicknesses. The net result is reduced overall design error due to the opposing effects of the errors from different sources. If the joint spacing is excessive, however, any beneficial effects of layer interaction can be overshadowed by excessive curling or warping stresses.

A thin separator layer, such as a curing compound or polyethylene sheeting, does not promote layer interaction. For those designs, all errors in thickness design are additive and lead to less conservative designs.

Current practice in mechanistic analysis also has many limitations, including the inability to consider interlayer friction in all but the most sophisticated general purpose three-dimensional finite-element analysis programs. The best measure of the adequacy of the designs obtained using existing thickness design procedures is field performance. The field performance of unbonded overlays has been generally very good; however, inadequate overlay thickness can be blamed for premature failure of some unbonded overlay projects. The development of a robust mechanistic thickness design procedure would greatly improve design reliability and help optimize unbonded overlay designs.

5.2.5 **Separator layer design**—The separator layer design is one of the primary factors influencing the performance of unbonded concrete overlays. The separator layer performs several important functions (Voigt et al. 1989; ERES 1999a):

- It isolates the overlay from underlying irregularities to allow uninhibited horizontal movement. Without adequate isolation, the underlying deterioration can cause localized locking of the overlay, which can result in reflection cracking;

- It provides adequate friction to ensure proper formation of joints in JPCP and cracks in CRCP. The use of materials that offer minimal frictional resistance, such as lime slurry or polyethylene sheeting, can cause problems with joints not forming at the intended intervals. The friction between pavement layers also contributes to the composite action that is beneficial to overlay performance; and

- It provides a level surface for the overlay construction.

Recognition that debonding of pavement layers is not essential nor always desirable for proper functioning of unbonded overlays is an important development in unbonded overlay design; however, modeling structural effects of the separator layer requires further research.

Many different separator designs have been used in unbonded overlay construction. The design that has given the best results are hot-mix asphalt layers at least 1 in. (25 mm) thick (Voigt et al. 1989; ACPA 1990b; Hall et al. 1993; ERES 1999a), which is also the design recommended in the 1993 AASHTO guide. In some applications, chip seals, slurry
seals, and sand-asphalt mixtures have also worked well; polyethylene sheeting, roofing paper, and curing compounds, on the other hand, have generally not worked well (Voigt et al. 1989; ACPA 1990b). Thin-layer materials are not recommended because they erode easily near joints, and they do not provide adequate isolation of the overlay concrete from underlying deterioration if the existing pavement has significant roughness from faulted joints and cracks (ACPA 1990b; ERES 1999a). A summary of general information for selecting separator layers is provided in Table 5.1.

### 5.2.6 Joint spacing

Joint spacing directly affects critical stresses in unbonded JPCP overlays. Depending on the pavement design, climate, season, and time of day, curling and warping stresses in JPCP can equal or exceed the load stresses. Because of the very stiff support provided by the underlying pavement, curling and warping stresses are more critical in unbonded overlays than in new pavements constructed on a granular base. Mechanistically, joint spacing is an essential input to thickness design for JPCP overlays, and the design thickness is only valid for the joint spacing assumed in the design analysis. Joint spacing, however, is not directly considered in either the AASHTO or the PCA overlay design procedures, and is another source of variability for the performance of unbonded overlays.

Because of the concerns about high curling and warping stresses, a shorter joint spacing is typically recommended for unbonded JPCP overlays than for new JPCP designs. The current AASHTO guide recommends limiting the maximum joint spacing to 21 times the slab thickness. For example, for an 8 in. (200 mm) overlay, the maximum recommended joint spacing is 14 ft (4.3 m). In general, this recommendation is reasonable for slab thicknesses up to approximately 9 in. (230 mm), except that joint spacing less than 12 ft (3.7 m) is not warranted because that would make the slabs shorter than the lane width. For thicker slabs (9.5 in. [240 mm] or more), the joint spacing based on 21 times the slab thickness is excessive, which increases the risk of premature slab cracking (especially top-down cracking). There are documented cases demonstrating that 20 ft (6 m) joint spacing can be excessive even for new pavements constructed 13 in. (325 mm) thick (Yu and Khazanovich 2001). In general, the risk of premature cracking in unbonded overlays can be greatly minimized by limiting the maximum joint spacing to 15 ft (4.6 m), even for very thick overlays.

Guidelines for joint spacing are sometimes given in terms of the $L/l$ ratio, where $L$ is the joint spacing, and $l$ is the radius of relative stiffness

$$ l = \left[ \frac{E_c \cdot D^3}{12 \cdot (1 - \mu^2) \cdot k} \right]^{0.25} \quad (5-3) $$

where:
- $l$ = radius of relative stiffness, in. (mm);
- $E_c$ = modulus of elasticity of concrete, psi (MPa);
- $D$ = slab thickness, in. (mm);
- $\mu$ = Poisson’s ratio; and

<table>
<thead>
<tr>
<th>General pavement condition</th>
<th>Repair work performed</th>
<th>Minimum recommended separator layer</th>
<th>Other factors to consider</th>
</tr>
</thead>
<tbody>
<tr>
<td>All concrete pavements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Badly shattered slabs</td>
<td>Yes—replaced full-depth</td>
<td>Thin</td>
<td>Subgrade repair/drainage</td>
</tr>
<tr>
<td>High deflection/pumping</td>
<td>Yes—replaced full-depth</td>
<td>Thin</td>
<td>Subgrade repair/drainage</td>
</tr>
<tr>
<td></td>
<td>Yes—seated</td>
<td>Thick</td>
<td>Drainage/dowels in overlay</td>
</tr>
<tr>
<td>Unstable slabs</td>
<td>Yes—undersealed</td>
<td>Thin</td>
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<td></td>
<td>Yes—seated</td>
<td>Thick</td>
<td>Drainage/dowels in overlay</td>
</tr>
<tr>
<td>Faulting ≤0.25 in. (6 mm)</td>
<td>None</td>
<td>Thin</td>
<td>Repair voids?—drainage</td>
</tr>
<tr>
<td>Faulting &gt;0.25 in. (6 mm)</td>
<td>Yes—cold-milled</td>
<td>Thin</td>
<td>Repair voids?—drainage</td>
</tr>
<tr>
<td>Surface-spalled/extensive D-cracking</td>
<td>Yes—filled with cold patch</td>
<td>Thin</td>
<td>Mismatch joints/dowels in overlay</td>
</tr>
<tr>
<td>Reactive aggregate</td>
<td>None</td>
<td>Thin</td>
<td>Drainage</td>
</tr>
</tbody>
</table>

| Jointed concrete pavements |                      |                                      |                          |
| Spalled and deteriorated joints | Yes—filled with cold patch | Thin | Mismatch joints |
|                               | None                  | Thick |                          |

| Continuously reinforced concrete pavements |                      |                                      |                          |
| Punchouts | Yes—replaced full-depth | Thick | Subgrade repair/drainage |

| Composite pavements |                      |                                      |                          |
| Medium- to high-severity reflective cracks | Yes—repair existing concrete | Thin | Mismatch joints from reflective cracks |
| Remove asphalt surface | Yes—repair existing concrete | Thin | Mismatch joints from reflective cracks |

*Thick separator layer > 0.5 in. (12 mm), thin separator layer < 0.5 in. (12 mm).

Particularly for heavy traffic routes.

Note: If poor load transfer exists (<50% deflection load transfer), a minimum hot-mix asphalt interlayer thickness of 1.5 in. (40 mm) is recommended.

### Table 5.1—General recommendations for selected separator layers (ACPA 1990b; ERES 1999a)

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<td></td>
<td>Yes—seated</td>
<td>Thick</td>
<td>Drainage/dowels in overlay</td>
</tr>
<tr>
<td>Faulting ≤0.25 in. (6 mm)</td>
<td>None</td>
<td>Thin</td>
<td>Repair voids?—drainage</td>
</tr>
<tr>
<td>Faulting &gt;0.25 in. (6 mm)</td>
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<td>Thin</td>
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<td>Thin</td>
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</tr>
<tr>
<td>Reactive aggregate</td>
<td>None</td>
<td>Thin</td>
<td>Drainage</td>
</tr>
</tbody>
</table>

| Jointed concrete pavements |                      |                                      |                          |
| Spalled and deteriorated joints | Yes—filled with cold patch | Thin | Mismatch joints |
|                               | None                  | Thick |                          |

| Continuously reinforced concrete pavements |                      |                                      |                          |
| Punchouts | Yes—replaced full-depth | Thick | Subgrade repair/drainage |

| Composite pavements |                      |                                      |                          |
| Medium- to high-severity reflective cracks | Yes—repair existing concrete | Thin | Mismatch joints from reflective cracks |
| Remove asphalt surface | Yes—repair existing concrete | Thin | Mismatch joints from reflective cracks |

*Thick separator layer > 0.5 in. (12 mm), thin separator layer < 0.5 in. (12 mm).

Particularly for heavy traffic routes.

Note: If poor load transfer exists (<50% deflection load transfer), a minimum hot-mix asphalt interlayer thickness of 1.5 in. (40 mm) is recommended.
Widened slabs are effective in improving both faulting and cracking performance (Smith et al. 1995). One study showed that the structural benefit of widened slabs is roughly equivalent to approximately 1 in. (25 mm) of additional slab thickness (Yu et al. 1995); however, widened slabs should be used with care on unbonded overlays because of the increased risk of longitudinal cracking. This is because unbonded overlays are constructed on very stiff foundations and are generally constructed thinner than new concrete pavements, both of which increase the potential for longitudinal cracking.

Although widened slabs are a better edge support design feature for new pavements, tied shoulders may be preferable for unbonded overlays. This is because of the increased risk of cracking due to high curling or warping stresses (resulting from stiff support conditions) of the widened slab. Furthermore, if the unbonded overlay is doweled, the effect of the widened slab on the faulting performance is minimal. Finally, because shoulder work is required for unbonded overlays, an opportunity exists for including tied concrete shoulders as part of the overlay project.

**5.2.10 Lane widening**—Construction of unbonded overlays may involve the widening of an old pavement with narrow traffic lanes, the addition of new travel lanes, or the extension of ramps. On such projects, the potential for longitudinal cracking is again a concern. In general, before the placement of the separator layer for the overlay, the widened portion should be provided with a cross section that closely matches that of the underlying pavement (AASHTO 1993). Either concrete or hot-mix asphalt can be used as fill beneath the widening (Fig. 5.2). A study conducted by the Minnesota Department of Transportation (MnDOT) showed no significant difference in performance between the widening accomplished using either hot-mix asphalt or concrete materials (Engstrom 1993). The main concern is to ensure that the widened portion provides adequate support without settlement or loss of support (ERES 1999a).

**5.2.11 Drainage**—The effectiveness of subsurface drainage on the performance of unbonded overlays is not well known because very little performance data are available. Because unbonded overlays are structurally similar to new concrete pavements constructed on a lean concrete base, the effects of edge drains may be similar. The possible benefits of properly designed, constructed, and maintained edge drains on new pavements include (Smith et al. 1995; ERES 1999b):

- Reduced pumping and faulting;
- Lower rate of cracking in CRCP; and
- Improved material performance, such as D-cracking or hot-mix asphalt separator layer stripping.

Some states, such as Minnesota and Pennsylvania, have experimented with permeable asphalt-treated separator layers; however, extensive stripping of these layers was observed on several projects investigated in Minnesota (ERES 1999a). Further research is needed to determine the

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**Fig. 5.1—Illustration of mismatched joints (ACPA 1990b).**

\[ k = \text{modulus of subgrade reaction, psi/in. or lb/in.}^3 \] (MPa/mm).

The maximum recommended \( L/k \) ratio for unbonded overlays is 4.5 to 5.5 (ERES 1999a). This recommendation is comparable to the guidelines given in the AASHTO guide for typical design conditions. Again, however, the results may be unconservative for thick slabs (higher than 9.5 in. [240 mm]) and overly conservative if the \( k \)-value is very high.

**5.2.7 Load transfer design**—Joint performance in unbonded concrete overlays is significantly better than in new JPCP construction because of the load transfer provided by the underlying pavement slabs (Hall et al. 1993; ERES 1999a). Mismatched joints are recommended for unbonded overlays (Fig. 5.1) to maximize the benefits of load transfer from the underlying pavement.

Doweled joints are still highly recommended for unbonded concrete overlays that will be subjected to heavy truck traffic to avoid corner breaks and to minimize faulting. Without dowels, the risk of corner breaks is high in unbonded overlays because of the very stiff support conditions.

**5.2.8 Mixture proportion**—As described in Chapter 2, the same concrete mixtures used for new construction are generally used for unbonded overlays. For projects in congested urban areas, however, extended lane closures due to pavement rehabilitation may be highly undesirable. For those projects, the use of fast-track paving may be considered to minimize traffic disruptions. Numerous fast-track concrete mixtures are available that can provide the strength required for opening to traffic in 4 hours, and the techniques for fast-track paving are well established (ACPA 1994a; FHWA 1994; ACI 325.11R). Fast-track paving has been used successfully on a number of projects where traffic congestion or accessibility is a critical issue (ACPA 1994a; ACI 325.11R). Little information, however, is available on the long-term performance and durability of pavements constructed using high-early-strength concrete mixtures.

**5.2.9 Edge support**—Edge support is a design feature provided to either reduce critical edge stresses or reduce the occurrences of edge-loading conditions that cause the highest stresses in concrete pavements. These features include tied concrete shoulders and widened slabs. In general, widened slabs are more effective than tied concrete shoulders in contributing to the performance of the pavement (Smith et al. 1995). The effectiveness of tied concrete shoulders depends on the effectiveness of the tie system, and shoulders constructed monolithically with the mainline pavement provide significantly better support than those paved separately. Even with an effective tie system, however, tied concrete shoulders have not significantly improved faulting performance, although they have been shown to be effective in reducing critical edge stresses (Smith et al. 1995; Yu et al. 1995).

**ACI COMMITTEE REPORT**
effectiveness of permeable separator layers; however, the appropriateness of using a permeable separator layer is questionable. This is because on an unbonded overlay, the permeable separator layer transfers the infiltrated water to joints and cracks in the underlying pavement. While the water in the permeable separator layer can be drained quickly, the permeable layer offers no advantage in draining the water in the underlying pavement. Without the permeable separator layer, less water is allowed into the underlying pavement. Therefore, while a permeable separator may improve the exposure condition for the overlay concrete, it may actually worsen the drainage condition for the underlying pavement.

Unfortunately, no information is currently available to substantiate any of the aforementioned performance benefits, so further research is needed to determine the effectiveness of edge drains on the structural performance of unbonded overlays. Based on the evaluation of edge drains in new concrete pavements, however, it might be that edge drains could improve material performance in whitetopping overlays (Smith et al. 1995; ERES 1999b).

5.2.12 Job-site considerations—Several job-site factors require special considerations, including bridge approaches, overhead clearances, and shoulders. At bridge approaches or underpasses, reconstruction of a short section may be necessary to satisfy vertical clearance requirements. Reconstruction requires sections at both ends to provide a smooth transition between the overlay and the reconstructed section. The recommended taper length for the transition is 300 to 500 ft (90 to 150 m) (ACPA 1990b). A similar transition section is also needed at bridge approaches. An example transition section is shown in Fig. 5.3.

The construction of unbonded overlays requires shoulder work. Either concrete or hot-mix asphalt shoulders could be provided, but as discussed previously, tied concrete shoulders may be advantageous for unbonded overlays, particularly in urban areas or in areas where the shoulder may at some point in the future be used as a travel lane. When used, it is important that the transverse joints in the concrete shoulder match those in the mainline pavement.

5.3—Construction

The construction of unbonded overlays involves limited preoverlay repairs, placement of the separator layer, and the placement of the overlay. Instead of preoverlay repairs, the existing pavement may be fractured to provide uniform support. These construction activities are briefly described in the following sections.

5.3.1 Preoverlay repair—The techniques for preoverlay repairs are the same as those for concrete pavement restoration. Recommended practices for these techniques are summarized in several references by the ACPA (1990b, 1994a, 1994b, 1995) and in an NHI training course (Hoerner et al. 2001).

As emphasized previously, unbonded overlays do not require significant preoverlay repairs. Typical repairs consist of full-depth repair of badly shattered slabs for JPCP and JRCP, and punchouts for CRCP. Section 4.2.3 provides additional discussion on preoverlay repair.

5.3.2 Slab fracturing—Slab fracturing may be appropriate if the existing pavement is extensively deteriorated or if it has severe material-related distress. Depending on the type of pavement, the existing pavement may be cracked and seated (JPCP), break and seated (JRCP or CRCP), or rubblized (all pavement types).

The aforementioned techniques are used more commonly before placing a hot-mix asphalt overlay, but there has been some use for concrete overlays as well. The techniques for slab fracturing are documented in numerous references, including Hoerner et al. (2001); Thompson (1999); Ksaibati et al. (1999); and Dykins and Epps (1987).

Weak subgrades can cause looseness and shifting of the fractured concrete, especially under saturated conditions, resulting in premature surface failures. For hot-mix asphalt overlays, rubblization is not recommended if the underlying subgrade is very weak (Ksaibati et al. 1999). Similar concerns may be applicable to unbonded overlays.

5.3.3 Separator layer placement—The placement of a separator layer does not involve any special or unusual construction techniques. The procedure depends on the interlayer material, but standard application procedures apply. Before placement of the separator layer, the existing pavement surface needs to be swept clean of any loose materials. Either a mechanical sweeper or an air blower may be used (ACPA 1990b).

With bituminous separator layers, precautionary steps may be needed to prevent the development of excessively high surface temperatures before concrete placement. If the surface of the separator layer is above 110 °F (43 °C), uncomfortable to touch with an open palm, water fogging is recommended to cool the surface (ACPA 1991b; McGhee 1994). An alternative to this is to construct the concrete overlay at night.

As described in Chapter 2, whitewashing of the bituminous surface using a lime slurry may also be performed to cool the
surface (ACPA 1990b). This practice, however, may lead to
debonding between the overlay and the separator layer, and
some degree of friction between the overlay and the separator
layer is believed to be beneficial to the performance of
unbonded overlays (ERES 1999a).

5.3.4 Placement, finishing, and texturing—The procedures
for placing and finishing concrete for unbonded overlays are
the same as those for new pavements. Refer to ACI 325.9R
for more specific information. The only reported problem
with placement and finishing for unbonded overlays is the
difficulty of anchoring dowel baskets in relatively thin
separator layers (ERES 1999a). While agencies need to be
aware of this potential problem, it is manageable. For
example, some contractors have used nail guns to secure the
baskets to the underlying concrete pavement. Alternatively,
pavers equipped with dowel bar inserters could be used to
avoid this problem altogether. Texturing of the finished
pavement surface is required to ensure adequate surface friction
of the roadway, as discussed in Section 2.6.3.

5.3.5 Curing—The curing of unbonded overlays generally
follows conventional practices as discussed in Section 2.6.5.
For unbonded overlays, particular attention should be paid to
the environmental conditions during construction to avoid
excessively high temperature gradients through the pavement
during curing. An excessive temperature gradient through
the slab at the time of concrete hardening can cause
locking-in of a significant amount of curling into slabs,
which can be deleterious to fatigue performance (Yu et al. 1995;
Yu et al. 1998a; Byrum 2000). The locked-in construction
curling is a special concern for unbonded overlays because of
the very stiff support conditions. The HIPERPav computer
program may be used to predict the potential for uncontrolled
early-age cracking of concrete pavements (including unbonded
overlays) for given environmental and mixture proportioning
inputs (McCullough and Rasmussen 1999a,b).

5.3.6 Joint sawing and sealing—As with new concrete
pavements, timely sawing is critical on unbonded overlays to
avoid random cracking. The same procedures and recommenda-
tions given for new pavements are applicable to unbonded
overlays. Joint sawing recommendations are given in numerous
references, including Okamoto et al. (1994) and the
NHI training course on pavement construction (ACPA
2000b). For fast-track projects, early-entry sawing may be
advantageous because that procedure allows sawing at
concrete strengths as low as 150 psi (1 MPa) flexural
strength using ultra-light saws (Hoerner et al. 2001).

5.4—Performance
The performance of unbonded overlays has generally been
very good. Unbonded overlays are usually considered a
long-term rehabilitation solution, and they are expected to
provide the level of service and performance life comparable
to those of new concrete pavements. A review of available
performance data shows that, for the most part, unbonded
overlays have been effective in meeting those expectations.
Sections 5.4.1 through 5.4.3 present a brief discussion of
the factors affecting the performance of unbonded overlays,
followed by an overview of field performance.

5.4.1 Factors affecting performance—The performance of
unbonded overlays is relatively insensitive to the condition
of the underlying pavement, and the overlays can be placed
with minimal preoverlay repair. Various factors, however,
can significantly influence the performance of unbonded
overlays, including:
- Separator design (type of material and layer thickness);
- Overlay design features (overlay thickness, joint spacing,
  load-transfer design, reinforcement design, and drainage
design);
- Traffic (axle weights and number);
- Climate (temperature and moisture conditions); and
- Construction quality and curing.

Further research is needed to quantify the effects of many
of these factors on the performance of unbonded overlays.
While there is significant experience in the design and construc-
tion of unbonded overlays, conclusive data documenting the
basis of many design and construction practices that have
become standard today are not available in many cases. For
example, the effects of the existing pavement condition or
the effects of preoverlay repairs on the performance of
unbonded overlays are not well documented.

5.4.2 Current state practices—The use of unbonded over-
lays dates back as early as 1916 (McGhee 1994). NCHRP
Synthesis 204 (McGhee 1994) catalogs 392 unbonded and
partially bonded overlay projects, over half of which were
constructed since 1970. An extensive survey of state practice
conducted in 1996 under NCHRP Project 10-41 (ERES
1999a) showed that 23 states have constructed unbonded
cracking concrete overlays since 1970. Of those, 11 states constructed
more than five projects during that period, with Colorado,
Iowa, Minnesota, Ohio, Pennsylvania, and Wisconsin each constructing 10 or more projects.

Historically, unbonded JPCP has been the most popular type of concrete resurfacing. NCHRP Synthesis 204 showed that
nearly two-thirds of concrete overlays are JPCP. The survey
conducted under NCHRP Project 10-41 showed similar
results, with unbonded JPCP overlays comprising 65% of the
projects reported (ERES 1999a). Trends have been toward
even greater use of JPCP designs for unbonded overlays.

Unbonded overlay thicknesses range from 3 to 13 in. (75
to 325 mm); however, very few projects have overlay thick-
nesses less than 6 in. (150 mm). A complete discussion of the
relationship between unbonded overlay and performance is
provided by Smith et al. (2002).

5.4.3 Overall field performance—In general, the
performance of unbonded overlays has been very good
(McGhee 1994; ERES 1999a). Where premature failures
have occurred, the failures are often attributed to (Voigt et al.
1989; McGhee 1994; ERES 1999a):
- Poor separator layer design;
- Excessive joint spacing; and
- Inadequate slab thickness.

A complete discussion on the relationship between
unbonded overlay and performance is provided by Smith et al.
(2002).

For JPCP, the risk of poor performance is high for overlays
thinner than 7 in. (175 mm). Figure 5.4 shows slab thickness
versus the probability of poor performance for unbonded JPCP overlays. The risk of poor performance is moderately high for 6 and 7 in. (150 and 175 mm) overlays, but significantly lower for overlays 8 in. (200 mm) or thicker.

For JRCP, slab thicknesses in the range of 9 to 11 in. (225 to 280 mm) all gave good performance, and slab thicknesses of 6 to 8 in. (150 to 200 mm) performed well at least 60% of the time. Although Smith et al. (2002) found poor performance for two 10 in. (250 mm) thick overlays, the main cause of poor performance was probably some factor other than slab thickness. One of the two poorly performing sections was constructed without a separator layer. For CRCP, the risk of poor performance is very high for an overlay thickness of 6 in. (150 mm) or less.

The report by Smith et al. (2002) suggests that establishing lower limits on unbonded overlay thickness may be desirable to avoid high-risk designs. JPCP and CRCP overlays 7 in. (175 mm) or thicker may be used, but improved design procedures are needed to improve overall design reliability.

The poor performance of two 10 in. (250 mm) thick JRCP overlays and one 8 in. (200 mm) thick CRCP overlay shows that not all design issues can be addressed through overlay thickness. Proper consideration of the condition of the underlying pavement, preoverlay repair needs, separator layer design, joint design, and reinforcement design are needed to obtain good performance.

**CHAPTER 6—CONVENTIONAL WHITETOPPING OVERLAYS**

6.1—Introduction

Whitetopping is the construction of a new concrete pavement over an existing asphalt pavement. It is a useful rehabilitation alternative for badly deteriorated asphalt pavements, especially those that exhibit such distresses as rutting, shoving (sideways flow of hot-mix asphalt), and alligator cracking (ACPA 1998). Because a relatively thick concrete surface is capable of bridging a significant amount of deterioration in the underlying asphalt pavement, minimal preoverlay repairs are needed for whitetopping. The whitetopping described in this chapter is contrasted with UTW and thin whitetopping, which are described in detail in Chapter 7.

A conventional whitetopping overlay is typically designed assuming an unbonded condition between the overlay and the underlying asphalt pavement; although in actuality, some bonding does occur. Thicknesses for whitetopping overlays are similar to those of new concrete pavements.

6.2—Design

6.2.1 General design considerations—Structurally, conventional whitetopping overlays are similar to new concrete pavements, and they are designed as such. Nevertheless, the design of whitetopping overlays involves the consideration of factors that are common to pavement rehabilitation projects, including:

- **Existing pavement condition**—The condition of the existing pavement affects the thickness design of whitetopping overlays and their economic feasibility. In general, whitetopping overlays are most appropriate for asphalt pavements that are extensively deteriorated. Pavements with excessive rutting, shoving, or alligator cracking are considered good candidates for conventional whitetopping overlays because these problems are not easily corrected with a hot-mix asphalt overlay;

- **Overlay pavement type**—The selection of the pavement type is usually a reflection of agency preference, but the condition of the existing pavement may be a factor that influences that decision. By far the most common type of whitetopping overlay is JPCP, but CRCP is also used. JRCP designs have also been used, but only a few have been built, and most of those were constructed before 1960 (McGhee 1994); and

- **Preoverlay repair**—Conventional whitetopping overlays do not require extensive preoverlay repairs, but the repair of certain types of distresses may be important to avoid localized failures. In general, the condition of the underlying pavement is more critical to the performance of CRCP whitetopping overlays. Additional information on preoverlay repairs is presented in Section 6.2.3.

In terms of assessing the feasibility of whitetopping as a rehabilitation alternative, several site factors should be considered:

- Traffic control;
- Shoulders; and
- Overhead clearance.

In urban areas where traffic congestion is already a daily problem, management of detour traffic during construction can be a critical issue (TRB 1998). At some point, pavement reconstruction is unavoidable; however, while rehabilitation alternatives with less severe lane closure requirements are still viable (such as a hot-mix asphalt overlay) the lane closure requirement can be a key factor that determines the feasibility of whitetopping overlays. For projects in congested areas, the use of fast-track paving techniques as discussed in ACI 325.11R may be appropriate to minimize lane closure times. Fast-track paving can be used to accomplish concrete pavement reconstruction and overlays with weekend lane closures (ACPA 1994a). Shoulder and overhead clearance considerations for whitetopping are similar to those for unbonded overlays discussed in Section 5.2.12.
6.2.2 Pavement evaluation—The evaluation of the existing pavement is an essential part of any overlay design. Field evaluation typically consists of a visual distress survey, deflection testing using a falling weight deflectometer, and coring. For thickness design, the main information that must be obtained is the foundation support value. One problem in determining this value for whitetopping is that for existing hot-mix asphalt pavements, the subgrade support value that is normally back-calculated is the resilient modulus \( MR \), whereas the input needed for concrete pavement design is the modulus of subgrade reaction \( k \)-value. Approximate correlations are available that can be used to estimate the \( k \)-value from back-calculated \( MR \) values or from other soil properties (AASHTO 1998). A correlation table is provided in ACI 325.12R.

The AASHTO “Guide for Design of Pavement Structures” (1993) provides a procedure for determining the composite \( k \)-value that reflects the structural contribution of the existing hot-mix asphalt pavement from a back-calculated subgrade resilient modulus; the PCA design procedure uses a similar approach (PCA 1984). The composite \( k \)-value is meant to represent the effective \( k \)-value at the top of the existing hot-mix asphalt pavement, and is determined considering the thickness and stiffness of the hot-mix asphalt layer. Research has shown, however, that this is not a realistic representation of the behavior of concrete pavements, and the concept of the composite \( k \)-value is inconsistent with the AASHTO design procedure (Darter et al. 1994; Hall et al. 1995). The more appropriate approach is to consider the contribution of the hot-mix asphalt layer in improving the bending stiffness of the concrete surface. This approach is adopted in the “Supplement to the AASHTO Guide for the Design of Pavement Structures” (AASHTO 1998) for the consideration of stabilized bases for new concrete pavement design.

As with any pavement rehabilitation project, variability in the existing pavement condition and in the subgrade are important considerations. The recommended practice is to break out any portion of the project with significantly different conditions as a separate section and design accordingly (AASHTO 1993).

6.2.3 Preoverlay repair—The most critical issue in considering repairs to the existing hot-mix asphalt pavement is to ensure that uniform support is provided for the concrete surface. To obtain the desired performance, areas of subgrade or base failure should be removed and replaced with a stable material (McGhee 1994). In addition, the repair of badly deteriorated areas is recommended; these include severe rutting, shoving, and potholes (ACPA 1998). Guidelines for preoverlay repairs of conventional whitetopping are given in Table 6.1.

6.2.4 Surface preparation—For conventional whitetopping, no special efforts are made to encourage bonding between the overlay and the underlying hot-mix asphalt surface; however, a surface preparation step may be required to address distortions in the existing hot-mix asphalt pavement surface or to correct surface profile. Three common methods of surface preparation are used for whitetopping:

- **Direct placement**—In this approach, the concrete overlay is placed directly on the existing hot-mix asphalt pavement after sweeping. Any ruts in the existing pavement are filled with concrete, resulting in a thicker concrete pavement in the rutted areas. In Iowa, county roads are often resurfaced with thickened-edge whitetopping by directly placing concrete on existing hot-mix asphalt sections (McGhee 1994). The direct placement method is recommended when the rutting on the existing hot-mix asphalt pavement does not exceed approximately 1 in. (25 mm). Consideration should also be given to the distorted surface profile in estimating the required material quantities. Additional survey of surface profiles may be required to allow this calculation; however, the additional cost of surveying is generally not as high as the cost of leveling the existing pavement surface (ACPA 1991b);

- **Milling**—In this approach, the existing hot-mix asphalt surface is milled to obtain a uniform surface. Milling can be used to resolve surface distortions and adjust cross slopes, with removal thicknesses typically ranging from 1 to 3 in. (25 to 75 mm) (ACPA 1991b). This approach requires less surveying time and cost than direct placement, but results in additional costs for milling (and, in some cases, disposal). Milling can be used in combination with direct placement, as only the parts of the project where the distortion is excessive need to be milled and direct placement can be used for the rest of the project (ACPA 1991b). If the surface is severely distorted, it may be more accurate to bid and control the overlay construction on a volume rather than an area basis; and

- **Placement of leveling course**—In this approach, a leveling course of hot-mix asphalt is used to produce a uniform surface for paving (ACPA 1991b). The leveling course typically consists of 1 to 2 in. (25 to 50 mm) of hot-mix asphalt. Because this method involves the additional expense of hot-mix asphalt work, this option is usually not considered when the distortion depths exceed

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**Table 6.1—Guidelines for whitetopping preoverlay repair (ACPA 1998)**

<table>
<thead>
<tr>
<th>General pavement condition</th>
<th>Recommended repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rutting (&lt;2 in. [50 mm])</td>
<td>None or milling⁠¹</td>
</tr>
<tr>
<td>Rutting (≥2 in. [50 mm])</td>
<td>Milling or leveling</td>
</tr>
<tr>
<td>Shoving</td>
<td>Milling</td>
</tr>
<tr>
<td>Potholes</td>
<td>Fill with crushed stone cold mixture or hot mixture</td>
</tr>
<tr>
<td>Subgrade failure</td>
<td>Remove and replace or repair</td>
</tr>
<tr>
<td>Alligator cracking</td>
<td>None</td>
</tr>
<tr>
<td>Block cracking</td>
<td>None</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>None</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>None</td>
</tr>
<tr>
<td>Raveling</td>
<td>None</td>
</tr>
<tr>
<td>Bleeding</td>
<td>None</td>
</tr>
</tbody>
</table>

⁠¹ Other factors to consider: adding edge drains, cost of direct placement on un repaired pavement versus milling, or leveling.

⁠² Consider deeper than standard joint sawing depth in the whitetopping pavement.
approximately 2 in. (50 mm) (McGhee 1994). In such cases, milling is typically less expensive (ACPA 1991b). A minimum hot-mix asphalt thickness of 2 in. (50 mm) (after any milling) is recommended for conventional whitetopping overlays (Grogg et al. 2001).

6.2.5 Thickness design—

6.2.5.1 Design procedures—Conventional whitetopping is designed as a new concrete pavement, treating the existing hot-mix asphalt pavement as a stabilized base. The required overlay thickness is determined using any established concrete design procedure for new pavements, such as the 1993 AASHTO methodology (AASHTO 1993), the PCA procedure (1984), or the 1998 AASHTO supplement procedure (AASHTO 1998). In all of these procedures, the overlay thickness is taken as the new concrete slab thickness required for the future traffic projections and for the given design conditions.

In addition to the design procedures described previously, simple design charts have also been developed for selecting thicknesses for whitetopping overlays (ACPA 1998). In these charts, the slab thickness is selected based on the number of trucks per day, the design concrete flexural strength, and the subordinate k-value. A minimum overlay thickness of 6 in. (150 mm) is recommended for conventional whitetopping of primary and interstate roads (ACPA 1998).

6.2.5.2 Bonding condition—In the design of conventional whitetopping overlays, the effects of any bonding between the concrete overlay and the underlying hot-mix asphalt layer is typically ignored, and the 1993 AASHTO and the 1984 PCA design procedures do not have any provisions for handling the effects of bonding.

The tendency for the concrete overlay to bond to the underlying hot-mix asphalt surface has long been recognized, and some degree of bonding nearly always occurs between the concrete overlay and the underlying hot-mix asphalt surface (Mack et al. 1992; Grove et al. 1993; Cole 1997; Tarr et al. 2000). The findings from these studies gave rise to the development of UTW overlays and to the concept of thin whitetopping overlays, both of which depend on achieving and maintaining a good bond between the concrete overlay and the underlying hot-mix asphalt. Design procedures that take into consideration the bonding between the concrete overlay and the underlying hot-mix asphalt pavement have been developed for these types of overlays (Tarr et al. 1998; Tarr et al. 2000; Wu and Sheehan 2002).

Incorporating the effects of bonding in the thickness design produces a thinner overlay; however, it is important to note that the long-term durability of the bond between the concrete overlay and the underlying hot-mix asphalt surface is not known. One study showed that concrete pavements constructed on a stabilized base nearly always exhibit bonded behavior (as indicated in falling weight deflectometer basin testing results), but long-term pavement performance (JPCP cracking) indicates unbonded behavior (Yu et al. 1998a). The debonding along the slab edges and corners (where the critical stresses occur in concrete pavements) could explain the apparently conflicting findings. A Colorado DOT study of the load response of instrumented slabs in the field also showed that whitetopping overlays can exhibit both bonded and unbonded behavior, depending on the temperature and loading conditions, and that actual bonding between the pavement layers is not necessary for the pavement to show bonded response (Yu et al. 1998b). Therefore, further study is needed to ensure that the long-term benefits of partial bonding can be counted on to ensure the satisfactory performance of whitetopping overlays of reduced thickness.

The effects of layer interaction are included in the “Supplement to the AASHTO Guide for the Design of Pavement Structures” (AASHTO 1998). The interaction between the concrete surface and stabilized base is handled through the use of a friction factor. The guide provides a range of recommended friction factors to account for a range of bonding conditions for different types of bases. Therefore, at least in principle, partial bonding can be considered by assigning the appropriate friction factor. The design thickness is insensitive to the friction factors in the range that is recommended for hot-mix asphalt base. Further validation of the design procedure may be needed to ensure the reliability of the design thicknesses obtained using this procedure.

The main advantages of conventional whitetopping are that it is an effective rehabilitation alternative for badly deteriorated hot-mix asphalt pavement and that it can be placed with minimal preoverly repairs. Note that in Table 6.1, no preoverlay is required for alligator cracking and other structural distresses; however, a badly deteriorated hot-mix asphalt pavement does not have a significant structural value to a concrete overlay, even if it is bonded to the overlay. Thus, if partial bonding were considered in the thickness design, consideration should also be given to the condition of the existing hot-mix asphalt pavement and the appropriate repairs made to ensure that the condition assumed in the design is valid.

6.2.6 Joint spacing—Transverse joint spacing directly affects the magnitude of critical stresses in JPCP whitetopping. Depending on the pavement design, the climate, season, and time of day, curling stresses in JPCP can equal or exceed the load stresses. Mechanistically, joint spacing is an essential input to thickness design for JPCP, and the design thickness is only valid for the joint spacing assumed in the design analysis. Joint spacing, however, is not directly considered in either the 1993 AASHTO or the 1984 PCA design procedures, and is a source of variability for the performance of concrete pavements. Joint spacing is directly considered as an input in the “Supplement to the AASHTO Guide for Design of Pavement Structures” (AASHTO 1998).

The maximum joint spacing recommended for conventional whitetopping constructed as JPCP is 21 times the slab thickness (ACPA 1998). For example, the recommended maximum joint spacing for an 8 in. (200 mm) whitetopping is 14 ft (4.3 m). As a basic rule of thumb, this guideline is generally considered adequate, although it may result in excessive joint spacing in slabs thicker than 9.5 in. (240 mm). For reliable performance, it is recommended that the joint spacing be directly considered in the thickness design.

6.2.7 Load-transfer design—Load-transfer designs for conventional whitetopping are identical to those for new
Concrete pavements discussed in Section 2.2.1. In general, doweled joints are recommended for all pavements that will be subjected to significant truck traffic. Experience in Wyoming and Utah showed that whitetopping projects built without dowels develop significant faulting in a few years under interstate traffic (McGhee 1994). Load-transfer without dowels develop significant faulting in a few years under interstate traffic (McGhee 1994). Load-transfer recommendations are summarized in Table 2.1.

The ACPA guidelines for preoverlay repairs for conventional whitetopping are given in Table 6.1 (ACPA 1998). The techniques for preoverlay repairs are the same as the repair techniques for hot-mix asphalt pavements. Recommended practices for these techniques are summarized in several references by the ACPA (1991b, 1998) and in an NHI training course manual (Grogg et al. 2001).

**6.3.1 Preoverlay repair**—As discussed in Section 6.2.3, conventional whitetopping requires minimal preoverlay repairs.

Recommended preoverlay repairs for conventional whitetopping include:

- Removal and replacement of areas of subgrade or base failure;
- Repair or removal of severe rutting, shoving, or other distortions; and
- Repair of potholes.

The ACPA guidelines for preoverlay repairs for conventional whitetopping are given in Table 6.1 (ACPA 1998). The techniques for preoverlay repairs are the same as the repair techniques for hot-mix asphalt pavements. Recommended practices for these techniques are summarized in several references by the ACPA (1991b, 1998) and in an NHI training course manual (Grogg et al. 2001).

**6.3.2 Surface preparation**—As discussed in Section 6.2.4, if surface distortions on the existing asphalt pavement are excessive (higher than 1 in. [25 mm]), either milling or the placement of a leveling course may be necessary. Milling and placement of a leveling course are a part of standard hot-mix asphalt paving techniques, and the procedures are no different for whitetopping overlays. The reference manual for the NHI training course “Hot-Mix Asphalt Construction” (NHI 1998) provides details of hot-mix asphalt construction techniques.

**6.3.3 Concrete placement, finishing, and texture**—The procedures for placing and finishing concrete for whitetopping overlays are the same as those for new pavements. Standard practices apply, and the NHI training course, “Construction of Portland Cement Concrete Pavements” (ACPA 2000c), provides a good summary of recommended practices for concrete placement and finishing.

When the air temperature is higher than approximately 90 °F (32 °C), the surface temperature of the existing hot-mix asphalt pavement can become excessive (ACPA 1998). Placing concrete on a hot asphalt surface can lead to cracking due to shrinkage and excessive thermal restraint stresses resulting from the large temperature difference between the concrete at hardening and overnight low temperatures. When the hot-mix asphalt pavement surface becomes uncomfortable to touch with an open palm, water fogging or whitewashing is recommended to reduce the surface temperature (ACPA 1998). Although the use of water fogging has worked well in reducing the surface temperature, the use of whitewashing should be used cautiously as it can reduce the friction between the concrete overlay and the hot-mix asphalt, which is believed to be beneficial to the performance of the whitetopping overlay. Texturing of the finished concrete pavement surface is required to ensure adequate surface friction of the roadway, as discussed in Section 2.6.3.

**6.3.4 Curing**—Curing of whitetopping overlays is no different than for new concrete pavement construction, as discussed in Section 2.6.5. Special attention to the temperature conditions during concrete placement may be warranted to placement of a concrete overlay. Concrete placement for whitetopping is no different than that for new construction.
avoid excessively high temperature gradients through the concrete during curing. An excessive temperature gradient through concrete at the time of concrete hardening can cause locking-in of a significant amount of curling into concrete slabs, which can be deleterious to fatigue performance (Yu et al. 1995, 1998b; Byrum 2000).

6.3.5 Joint sawing and sealing—As with new concrete pavements, timely sawing is critical to avoid random cracking for whitetopping overlays. The same procedures and recommendations given for unbonded overlays in Section 5.3.6 are applicable to whitetopping overlays.

The saw-cut depth is of particular concern for conventional whitetopping overlays because the distortions in the underlying hot-mix asphalt pavement can effectively increase the slab thickness. This is illustrated in Fig. 6.2. A minimum saw-cut depth of one-third of the greatest concrete thickness is recommended (ACPA 1998). A deeper cut should be made at locations where the overlay thickness as placed is more than 1 in. (25 mm) greater than the nominal thickness. For early-entry sawing, a shallower saw cut may be allowable (ACPA 1998).

6.4—Performance

6.4.1 Factors affecting performance—The performance of conventional whitetopping overlays is insensitive to the condition of the underlying hot-mix asphalt pavements, and in most cases, the overlays can be placed with minimal preoverlay repair. Exceptions are when the asphalt is so extensively cracked as to be nearly disintegrated, or where the subgrade has failed. The same factors that affect the performance of new concrete pavements affect the performance of conventional whitetopping overlays, including:

- Overlay design features (overlay thickness, joint spacing, load-transfer design, reinforcement design, and drainage design);
- Traffic (axle weights and number);
- Climate (temperature and moisture conditions); and
- Construction quality and curing.

For the most part, existing design procedures have been effective in producing workable design thicknesses for whitetopping. There is, however, a possibility that conventional design practices may be overly conservative in some cases because the bond effects have been ignored.

6.4.2 State practice—Whitetopping has been used by many highway agencies, including California, Iowa, Missouri, Nebraska, Nevada, Texas, Wyoming, and Utah, and has become an increasingly popular technique for rehabilitating deteriorated hot-mix asphalt pavements (McGhee 1994). For example, of the 189 whitetopping projects listed in NCHRP Synthesis 204 (McGhee 1994), 125 of those were built since 1980. Between 1970 and 1980, whitetopping was used in numerous projects to upgrade the existing pavement to the interstate standards (Webb and Delatte 2000).

Whitetopping thicknesses typically range from 8 to 12 in. (200 to 300 mm) when placed on primary interstate highways, and from 5 to 7 in. (125 to 175 mm) when placed on secondary roads (ACPA 1998). JPCP designs are by far the most common type of whitetopping, although some states have constructed CRCP whitetopping overlays.

The effect of bond between the concrete overlay and the underlying hot-mix asphalt has been gaining more attention since the early 1990s in the design of whitetopping overlays. In 1991, the Iowa DOT conducted a study to determine the bond contribution to whitetopping overlays (Grove et al. 1993). Their report concluded that the existing hot-mix asphalt pavement does contribute significantly to the structural capacity of the concrete overlay, and that the bond effects should be considered in the thickness design, at least in cases where the traffic loads are not expected to cause stresses that exceed the bond strength. The Colorado DOT developed a mechanistic design procedure for thin (5 to 7 in. [125 to 175 mm]) whitetopping that takes into consideration the effects of partial bonding between the pavement layers (Tarr et al. 1998, 2000; Wu and Sheehan 2002).

6.4.3 Field performance—The field performance of whitetopping overlays has generally been very good. The majority of whitetopping overlays have provided good to excellent performance (Lokken 1981; Hutchinson 1982; McGhee 1994). The success of this design is often attributed to the uniform support and bond provided by the underlying hot-mix asphalt pavement (Hutchinson 1982; Grove et al. 1993; McGhee 1994).

California has used whitetopping extensively since the 1960s, and has enjoyed considerable success with the treatment. For example, numerous highway pavement sections were whitetopped with 7 to 9 in. (175 to 225 mm) thick nondoweled JPCP in the 1960s and 1970s, and these were reported to be performing well after up to 20 years of service (Lokken 1981; Hutchinson 1982).

Iowa also has had outstanding performance from whitetopping overlays, many of which have been placed on their county highway system. For example, beginning in the late 1970s, three Iowa counties (Dallas, Boone, and Washington) began paving with whitetopping overlays, and since that time, an average of 19 miles (31 km) of county pavement are whitetopped each year (ACPA 2000d). In most cases, the concrete overlays are placed directly on the existing hot-mix asphalt with little preparation other than sweeping (ACPA 2000d). In addition, the concrete overlays are constructed with 15 ft (4.6 m) joint spacings and thickened-edge slab designs, in which the center of the pavement is constructed 5 or 6 in. (125 or 150 mm) thick, and the outer edges are constructed 6 or 7 in. (150 or 175 mm) thick (ACPA 2000d). After 22 years of service, the oldest whitetopping overlays have required minimal maintenance, and are performing well (ACPA 2000d).
Where the performance of whitetopping overlays has not been satisfactory, the problem can often be traced to a design flaw or inadequacy. For example, the Wyoming DOT reported that nondoweled whitetopping overlays developed significant faulting after a few years of interstate highway traffic (McGhee 1994). Similar findings were made on nondoweled whitetopping overlays in Utah (McGhee 1994).

CHAPTER 7—ULTRA-THIN AND THIN WHITETOPPING OVERLAYS

7.1—Introduction

As described in Chapter 2, UTW and thin whitetopping are the placement of a thin concrete pavement over an existing hot-mix asphalt pavement. Effective bond between the concrete overlay and the existing hot-mix asphalt pavement is critical to the performance of this rehabilitation technique because the existing hot-mix asphalt pavement is being relied upon to carry part of the traffic load (Mack et al. 1998). Factors differentiating UTW from conventional whitetopping include (ACPA 1998):

- The use of thin concrete surfacings (between 2 and 4 in. [50 and 100 mm] for UTW and between 4 and 8 in. [100 and 200 mm] for thin whitetopping);
- The need for extensive surface preparation to promote significant bonding between the concrete overlay and the hot-mix asphalt pavement;
- The use of short joint spacings (generally between 2 and 6 ft [0.6 and 1.8 m]); and
- In many cases, the use of high-strength concrete mixtures to provide early opening times and the inclusion of synthetic fibers (commonly polypropylene or polyolefin) to help control plastic shrinkage cracking.

See ACI 544.1R for use of fibers.

UTW overlays are intended for parking lots, residential streets, low-volume roads, general aviation airports, and hot-mix asphalt intersections where rutting is a problem (ACPA 1998). UTWs usually are applied where a substantial thickness of hot-mix asphalt exists (higher than 3 in. [75 mm] after any surface preparation) because of the reliance on the hot-mix asphalt to carry a significant part of the load (ACPA 1998).

The project that served to give rise to the consideration of UTW overlays as a viable rehabilitation alternative was constructed in 1991 on a landfill access road in Louisville, Ken. (Risser et al. 1993). This experimental project featured two different slab thicknesses and varying slab dimensions. The UTW pavements constructed in that project performed very well, carrying far more traffic than originally anticipated. The outstanding performance of that project created a widespread interest in the continued use and development of the technology, and since 1992, over 200 UTW projects have been constructed in at least 35 states (ACPA 2000a). The NCHRP has published NCHRP Synthesis 338, “Thin and Ultra-Thin Whitetopping” (2004).

7.2—Design

7.2.1 General design considerations—When contemplating the use of UTW overlays, several general considerations regarding their applicability should first be evaluated. These considerations include:

- Detailed evaluation of existing pavement—A thorough examination of pavement deficiencies and the causes of deterioration should be made before selecting UTW as a treatment alternative. Generally speaking, UTWs are intended to be placed on existing hot-mix asphalt pavements that are exhibiting rutting, shoving, and other surface distresses. Severely deteriorated hot-mix asphalt pavements with significant structural deterioration, inadequate base/subbase support, poor drainage conditions, or stripping of the hot-mix asphalt layers are not candidates for UTW overlays if these conditions are extensive throughout a project. Furthermore, a minimum asphalt thickness (after milling) is required to provide the necessary support to the UTW overlay. ACPA (1998) suggests a minimum asphalt thickness of 3 in. (75 mm), whereas Silfwerbrand (1997) suggests a minimum asphalt thickness of 6 in. (150 mm), unless the subgrade is stiff or only light traffic loads are anticipated;
- Traffic evaluation—UTW overlays are intended for pavements subjected to lower traffic levels. Consequently, traffic studies should be performed to ensure that the truck traffic levels are such that a UTW overlay is still appropriate. The design life of the UTW overlay will vary depending on the traffic to which it is exposed;
- Surface preparation—The success of UTW overlays depends largely on achieving an effective bond between the new overlay and the existing asphalt pavement. This is accomplished by milling the asphalt surface to not only enhance the bond, but also to remove any surface distress or distortions; and
- Lane closures—Certain locations, such as urban intersections, may present specific constraints on available lane closure times and the management of detoured traffic. In these cases, the use of fast-track paving may be considered for the UTW to minimize lane closure times. Additional information on fast-track paving is found in ACI 325.11R and references by FHWA (1994) and ACPA (1994a).

Because milling is performed before the placement of UTW overlays, vertical overhead clearances, the matching of adjacent shoulder and traffic lane elevations, and the maintenance of curb reveals are generally not a problem. Often, the UTW can be placed as an inlay, using adjacent (unmilled) asphalt as side formwork, thereby lowering costs and facilitating the construction of a smooth pavement (Fig. 7.1).

7.2.2 Pavement evaluation—As with any rehabilitation technique, the existing pavement should be evaluated as part of the design process. This is necessary to ensure that the existing asphalt pavement is structurally adequate to help carry the anticipated traffic loads. If the load-carrying capacity of the existing pavement is too low, there is a risk that the overlaid pavement will crack prematurely from traffic loading (Silfwerbrand 1997).

The structural adequacy of the existing asphalt pavement can be assessed through an examination of the type, severity, and extent of the existing distresses and through deflection
testing using a falling-weight deflectometer. Falling-weight deflectometer results can provide information on the stiffness of the asphalt pavement and on the subgrade support conditions, which are needed in the design process. Furthermore, falling-weight deflectometer results can help to reveal the variability of these properties over the length of the project, and can help identify localized weak areas requiring strengthening. As discussed in Chapter 6, the back-calculation process on an existing asphalt pavement produces a subgrade resilient modulus value $M_R$, and this should be converted to a modulus of subgrade reaction $k$-value for whitetopping design. Approximate correlations are available that can be used to estimate the $k$-value from back-calculated $M_R$ values or from other soil properties (AASHTO 1998). A correlation table is provided in ACI 325.12R for estimating the $k$-value on the basis of other parameters.

In particular, the existing asphalt pavement should be assessed to ensure that there will be enough asphalt to form a composite section, and that the asphalt is not stripped. Cores should be extracted from the existing pavement at several locations to ensure that there is enough asphalt and that there are no visual indications of stripping.

7.2.3 Preoverlay repair—UTW overlays may require some preoverlay repair of the existing asphalt pavement to achieve the desired level of performance. Because the existing asphalt pavement is being relied upon to carry part of the traffic loading, any deteriorated areas that would otherwise detract from its load-carrying capacity should be repaired (Grogg et al. 2001). This includes potholes, areas with moderate to severe alligator cracking, and other areas exhibiting structural inadequacies. In addition, milling of the existing asphalt surface is required to remove rutting, restore profile, and provide a roughened surface to enhance bonding between the new concrete overlay and the existing hot-mix asphalt pavement (ACPA 1998). The thickness of the existing asphalt pavement should also be verified with cores to help determine appropriate milling depths to ensure that sufficient asphalt thickness remains after milling to contribute structurally to the UTW overlay.

7.2.4 Thickness design—Because it is a relatively new technology, it has been only in the last several years that research activities have focused on the development of a formal design procedure for UTW and thin whitetopping overlays. The procedures discussed previously—such as those of AASHTO and PCA—that are valid for other overlay types do not apply to UTW and thin whitetopping. The design of UTW is more complex than conventional overlay design because of the following factors (ACPA 1998, 1999b):

- The bond between the concrete and the asphalt pavement;
- The short joint spacings associated with the design; and
- Concrete mixtures used in UTW projects often have higher strength and may use fibers.

As previously described, the bond between the concrete and the asphalt pavement is particularly critical to the performance of UTW overlays. Bond between these layers enables the pavement to act monolithically, which greatly reduces the magnitude of the stresses that develop in the pavement structure (ACPA 1998, 1999b).

An interim design procedure for estimating the load-carrying capacity and service life of UTW projects has been developed based on field performance results, instrumented slabs, and three-dimensional, finite-element modeling (Wu et al. 1997). The design procedure considers the development of critical stresses at both the corner and joint locations of a slab, and also incorporates the effects of temperature-induced stresses (Wu et al. 1997). Based on that procedure, two sets of simplified design charts were developed, each for a specific truck category (ACPA 1998, 1999b):

- Axle load Category A (for low-truck-volume facilities) uses an assumed axle load distribution with a maximum single-axle load of 18,000 lb (80 kN) and a maximum tandem-axle load of 36,000 lb (160 kN); and
- Axle load Category B (for medium-truck-volume facilities) uses an assumed axle load distribution with a maximum single-axle load of 26,000 lb (116 kN) and a maximum tandem-axle load of 44,000 lb (196 kN).

The assumed axle load distributions for each axle load category are defined in a document by ACPA (1992). One set of design tables (Tables 7.1 and 7.2) has been developed for low-truck-volume facilities, and one set of design tables (Tables 7.3 and 7.4) has been developed for medium-truck-volume facilities. The output of the tables is the allowable number of trucks per lane (in thousands) for an assumed axle load distribution and a given UTW design, which is defined in terms of subgrade support, concrete flexural strength, asphalt thickness, concrete pavement thickness, and joint spacing. Thus, in using the tables, the adequacy of a selected design is evaluated, rather than the determination of a specific slab thickness design. The ACPA web site provides a UTW calculator (http://www.pavement.com/PavTech/Tech/UTWCalc/Main.asp) that automates this design procedure.

As an example of using the tables, assume that a UTW overlay is being contemplated for a city street subjected to truck traffic in axle load Category B. The existing subgrade has a $k$-value of 200 psi/in. (54 kPa/mm), and the existing asphalt pavement will be 4 in. (100 mm) thick after milling. If the UTW will be 3 in. (75 mm) thick with a flexural strength of 700 lb/in. $^2$ (5 MPa) and a joint spacing of 3 ft (0.9 m), then it should be able to withstand 284,000 trucks in axle

Fig. 7.1—UTW placement as inlay.
Table 7.1—Allowable number of trucks (in thousands) per UTW traffic lane*

<table>
<thead>
<tr>
<th>Average flexural strength, psi (MPa)</th>
<th>$h_2$, asphalt thickness, in. (mm)</th>
<th>$h_1$, UTW thickness</th>
<th>Joint spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 in. (50 mm)</td>
<td>3 in. (75 mm)</td>
<td>4 in. (100 mm)</td>
</tr>
<tr>
<td>700 (4.8)</td>
<td>3 (75)</td>
<td>60 (150) or more</td>
<td>462 (1170)</td>
</tr>
<tr>
<td>700 (4.8)</td>
<td>4 (100)</td>
<td>56 (140) or more</td>
<td>384 (952)</td>
</tr>
<tr>
<td>700 (4.8)</td>
<td>5 (125)</td>
<td>169 (422) or more</td>
<td>765 (1870)</td>
</tr>
<tr>
<td>700 (4.8)</td>
<td>6 (150) or more</td>
<td>507 (1249)</td>
<td>882 (2082)</td>
</tr>
</tbody>
</table>

*Axle load Category A, $k = 100$ psi/in. or lb/in.² (27 kPa/mm) (ACPA 1998, 1999b).

Table 7.2—Allowable number of trucks (in thousands) per UTW traffic lane*

<table>
<thead>
<tr>
<th>Average flexural strength, psi (MPa)</th>
<th>$h_2$, asphalt thickness, in. (mm)</th>
<th>$h_1$, UTW thickness</th>
<th>Joint spacing</th>
</tr>
</thead>
<tbody>
<tr>
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<td>462 (1170)</td>
</tr>
<tr>
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<td>4 (100)</td>
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<td>384 (952)</td>
</tr>
<tr>
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</tr>
<tr>
<td>700 (4.8)</td>
<td>6 (150) or more</td>
<td>507 (1249)</td>
<td>882 (2082)</td>
</tr>
</tbody>
</table>

*Axle load Category A, $k = 200$ psi/in. or lb/in.² (54 kPa/mm) (ACPA 1998, 1999b).

Table 7.3—Allowable number of trucks (in thousands) per UTW traffic lane*

<table>
<thead>
<tr>
<th>Average flexural strength, psi (MPa)</th>
<th>$h_2$, asphalt thickness, in. (mm)</th>
<th>$h_1$, UTW thickness</th>
<th>Joint spacing</th>
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</thead>
<tbody>
<tr>
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<td>3 in. (75 mm)</td>
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<tr>
<td>700 (4.8)</td>
<td>3 (75)</td>
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<td>462 (1170)</td>
</tr>
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<td>5 (125)</td>
<td>169 (422) or more</td>
<td>765 (1870)</td>
</tr>
<tr>
<td>700 (4.8)</td>
<td>6 (150) or more</td>
<td>507 (1249)</td>
<td>882 (2082)</td>
</tr>
</tbody>
</table>

*Axle load Category B, $k = 100$ psi/in. or lb/in.² (27 kPa/mm) (ACPA 1998, 1999b).

Dowel bars, tie bars, and other embedded steel items are not used in UTW overlays. This is because the thin UTW slabs make their installation impractical, and effective load transfer at joints is expected to be provided by the aggregate interlock across the abutting joint faces and by the stiff support of the underlying asphalt pavement.

Thickened slabs are required for UTW overlays at transition areas between the concrete overlay and an adjacent asphalt pavement because impact loadings from traffic may induce high stresses in the UTW and cause cracking. A suggested transition detail is shown in Fig. 7.2 (ACPA 1998).

To date, specific design procedures have not been established for thin whitetopping. The simple design charts developed for selecting thicknesses for whitetopping overlays in ACIA EB 210P (ACPA 1998), however, may be conservatively used to design thin whitetopping. These charts do not consider the effect of bond between the thin whitetopping overlay and existing asphalt, but they do account for the support provided by the existing asphalt to the overlay.
Drainage survey to identify moisture-related distresses and establish a process, it is always advisable to conduct a thorough evaluation of the existing pavement, adding an overlay will not correct the problem and deterioration of the pavement system will continue. Poor drainage may contribute to asphalt stripping.

As seen in this table, common characteristics of many of the mixtures are high cementitious material (cement and fly ash) contents, low water/cement (including fly ash) ratios, and an accelerator (typically 0.75 in. [19.0 mm]), and the use of synthetic fibers. As described in Chapter 2, the introduction of the fibers is expected to improve the toughness and postcracking behavior of the concrete and help control plastic shrinkage cracking. Polypropylene and polyolefin fibers are the two most commonly used synthetic fibers in UTW overlays.

7.2.6 Mixture proportions—Concrete mixtures used in UTW overlays are often high-strength mixtures, and generally contain fibers (ACPA 1998). Depending upon the lane closure requirements of the particular UTW project, fast-track paving mixtures may also be used to achieve compressive strengths over 3000 psi (21 MPa) within 24 hours (Mack et al. 1998). Such mixtures often employ Type III cement, higher cement contents, a low water/cement ratio (typically 0.35 to 0.43), and an accelerator to achieve the required strength for the specified opening time. Details of accelerated or fast-track paving are provided in ACI 325.11R.

Table 7.5—Sample concrete mixture proportions for UTW projects

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement, lb/yd³</td>
<td>800</td>
<td>373</td>
<td>610</td>
<td>520</td>
<td>450</td>
<td>550</td>
<td>610</td>
</tr>
<tr>
<td>Fly ash, lb/yd³</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>92</td>
<td>120 (Class C)</td>
<td>--</td>
</tr>
<tr>
<td>Coarse aggregate, lb/yd³</td>
<td>1710</td>
<td>1661</td>
<td>1693</td>
<td>1835</td>
<td>1552 (3/4 minus)</td>
<td>1552 (3/4 minus)</td>
<td>1658</td>
</tr>
<tr>
<td>Fine aggregate, lb/yd³</td>
<td>1098</td>
<td>1363</td>
<td>3119</td>
<td>1126</td>
<td>1287</td>
<td>1287</td>
<td>1334</td>
</tr>
<tr>
<td>Water, lb/yd³</td>
<td>280</td>
<td>244</td>
<td>224</td>
<td>266</td>
<td>245</td>
<td>240</td>
<td>239</td>
</tr>
<tr>
<td>w/cm (including fly ash)</td>
<td>0.35</td>
<td>0.43</td>
<td>0.37</td>
<td>0.43</td>
<td>0.43</td>
<td>0.37</td>
<td>0.39</td>
</tr>
<tr>
<td>Air content, %</td>
<td>5</td>
<td>6</td>
<td>6.5</td>
<td>5 to 8</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Fiber type(s)/content</td>
<td>Polypropylene</td>
<td>None/Polystyrene</td>
<td>None/Polystyrene</td>
<td>Polypropylene</td>
<td>Polypropylene</td>
<td>Polyolefin</td>
<td>Polyolefin</td>
</tr>
<tr>
<td></td>
<td>3 lb/yd³</td>
<td>3 lb/yd³</td>
<td>3 lb/yd³</td>
<td>3 lb/yd³</td>
<td>3 lb/yd³</td>
<td>3 lb/yd³</td>
<td>3 lb/yd³</td>
</tr>
<tr>
<td>Other admixtures</td>
<td>High-range water reducer</td>
<td>--</td>
<td>--</td>
<td>Water reducer</td>
<td>Water reducer</td>
<td>Water reducer</td>
<td>Water reducer</td>
</tr>
<tr>
<td>Strength test results, psi</td>
<td>N/A</td>
<td>N/A</td>
<td>Compressive: 4975 at 1 day 8033 at 28 days</td>
<td>Compression: 9100 at 14 days 5200 at 28 days</td>
<td>Compression: 4400 at 14 days 5300 at 28 days</td>
<td>Compression: 2755 at 1 day 6815 at 28 days</td>
<td>Compression: 870 at 28 days</td>
</tr>
</tbody>
</table>

Note: Unit conversions: 1 lb/yt³ = 0.593 kg/m³; 1 psi = 0.00689 MPa.

7.2.7 Drainage—As part of the pavement evaluation process, it is always advisable to conduct a thorough drainage survey to identify moisture-related distresses and develop solutions that address these distresses. If poor drainage conditions are contributing to the deterioration of the existing pavement, adding an overlay will not correct the problem and deterioration of the pavement system will continue. Poor drainage may contribute to asphalt stripping.

The benefits of including edge drains as part of an UTW overlay project have not been documented. In urban areas, UTW overlays often incorporate drainage inlets that are tied to storm drain systems; in rural areas, regrading and reestablishment of the ditches may be required to facilitate drainage.

7.3—Construction

The construction process for UTW and thin whitetopping overlays includes preoverlay repairs, surface preparation, concrete placement and finishing, curing, and sawing and sealing. Although conventional concrete paving practices are employed for UTW overlays, some specific construction considerations are particularly critical to the performance of the design, and will be highlighted in this section. A construction specification guideline for UTW overlays is available from ACPA (1999a).

7.3.1 Preoverlay repair—As described in Section 7.2.3, some preoverlay repair of the existing asphalt pavement is required to obtain the desired level of performance. This is because the existing asphalt pavement will be carrying part of the traffic load, so any structural deficiencies in the
existing asphalt pavement should be corrected before the placement of the UTW overlay. Among the types of preoverlay repair activities typically required for UTW overlays are (McGhee 1994; ACPA 1998):

- Localized repair of failed areas caused by loss of base or subgrade support;
- Filling of medium- and high-severity potholes; and
- Localized repair of medium to severe alligator cracking. If significant alligator cracking exists throughout the project, this suggests a structural inadequacy and the pavement may not be a suitable candidate for UTW.

These activities should follow conventional asphalt patching practices. In the case of patching of alligator cracking, it is important that the entire distressed area be removed and replaced through the entire thickness of the asphalt pavement.

At least one highway agency has experimented with the use of cold-in-place recycling (CIR) of the existing asphalt pavement before the placement of the UTW overlay. On part of the Route 21 project near Belle Plaine, the Iowa DOT used a continuous recycling train to first mill the existing asphalt pavement to a depth of 3.75 in. (95 mm), resize the removed material and mix it with an emulsion, and place the rejuvenated material back on the pavement surface (Cable et al. 1999).

7.3.2 Surface preparation—Milling of the existing asphalt pavement is critical to the performance of the UTW overlay. Not only does it remove rutting and restore the surface profile, it also provides a roughened surface to enhance the bonding between the new concrete overlay and the existing asphalt (ACPA 1998). This will increase the load-carrying capacity of the pavement system by enabling it to behave as a monolithic structure.

Milling should be conducted after the existing asphalt pavement has been patched. Milling machines use carbide-tipped bits attached to a revolving drum to cut away the existing asphalt. A variety of milling machines are available for asphalt removal, ranging from small equipment with narrow, 1 ft (0.3 m) wide drums to larger equipment with full-lane width (12 ft [3.7 m]) wide drums. Although some equipment can remove asphalt depths up to 12 in. (300 mm) in a single pass, common asphalt removal depths in preparation for UTW overlays are 1 to 3 in. (25 to 75 mm). The amount of asphalt removal for a particular project will depend on the type and severity of distress (especially the depth of rutting or other surface distortions) and the thickness of the asphalt pavement. After milling, the remaining asphalt pavement should be checked to ensure adequate thickness remains for the composite pavement.

After the pavement has been milled, the pavement surface should be cleaned to help ensure bonding between the existing asphalt and the new concrete overlay. This may be accomplished by air blasting or power brooming, but occasionally water blasting or sandblasting may be required to remove any slurry or residue from the milling. If water blasting or washing operations are used, the surface should be allowed to dry before the placement of the concrete overlay (ACPA 1998).

7.3.3 Placement, finishing, and texturing—Once the surface of the existing asphalt pavement has been prepared, the concrete overlay is placed. Paving is accomplished using either fixed-form or slipform construction, the selection of which will depend on the size of the project and any geometric constraints. In either case, conventional concrete paving practices and procedures are followed. Primary activities in this part of the operation include spreading, consolidation, screeding, and float finishing. Texturing is discussed in Section 2.6.3.

7.3.4 Curing—Effective curing of the new UTW overlay promotes continued cement hydration and strength gain by controlling the rate of moisture loss in the concrete slabs. Although curing is important to all concrete pavements, it is even more critical to UTW overlays because their high surface area-to-volume ratio make them more susceptible to rapid moisture loss. Curing is most often accomplished through the application of a curing compound immediately after the final texturing of the concrete surface, as discussed in Section 2.6.5.

7.3.5 Joint sawing and sealing—Timely joint sawing is required to establish the contraction joints in the concrete pavement and prevent random cracking. Because of the great amount of joint sawing required on UTW overlays, joint sawing should commence as soon as the concrete has developed sufficient strength such that the joints can be cut without significant raveling or chipping. This will typically be within approximately 3 to 6 hours after concrete placement. The contractor should ensure that there are sufficient saw-cutting crews available for the work and that all crews are familiar with the prescribed joint-sawing patterns. Because of the need to get on the pavement as soon as possible, the use of lightweight early-entry saws is particularly advantageous for UTW overlay construction.

Criteria for saw-cut depths on UTW overlays have not been established, but a minimum 1 in. (25 mm) deep cut appears to perform satisfactorily for both transverse and longitudinal joints (ACPA 1998). The joints are typically sawed to a width of 0.12 in. (3 mm). Generally, the joints in UTW projects are not sealed, although a few agencies have constructed experimental UTW sections comparing sealed and nonsealed joints.

7.4—Performance

Because this is a new and evolving technology, very little long-term performance data are available for UTW and thin whitetopping overlays. The available data suggest that UTW overlays are a viable pavement rehabilitation alternative for low-volume roadways. Performance of specific projects is discussed in Smith et al. (2002).

7.4.1 ACPA UTW performance evaluations—In 1995 and 1996, the ACPA conducted detailed condition surveys on nine UTW projects: six in Tennessee and three in Georgia. The purpose of these surveys was to examine the early performance of UTW overlays, and the nine projects were selected primarily because they were some of the older UTW overlays (Cole 1997).

Based on the results of the condition surveys, which represent approximately 4 to 5 years of performance data, the following conclusions were drawn (Cole 1997):

- Nine of the 10 sections are rated in excellent condition;
Some cracks have occurred on the various concrete slabs, but most of these cracks are low severity (less than 0.02 in. [0.5 mm] wide) and do not appear to be affecting pavement ride quality;

The first and last panels (approach and leave ends) of the UTW overlays contain a higher percentage of cracking than the rest of the project. This is believed to be the result of impact loading as the wheel crosses from the adjacent asphalt pavement to the UTW overlay; and

Sections with the best condition have the smallest panel size and a significant underlying hot-mix asphalt thickness.

7.4.2 Thin whitetopping performance—To date, only one thin whitetopping project has been documented in the literature. This pavement was 6 in. (150 mm) thick with 6 ft (1.8 m) joint spacing and was constructed on U.S. 78 in Jasper, Ala., in October 2001. The thin whitetopping was constructed as an inlay in the traffic lanes at an intersection (Delatte et al. 2001). The project was inspected 2 years after construction, and no distress was observed.

CHAPTER 8—REFERENCES

8.1—Referenced standards and reports

The latest editions of the standards and reports listed below were used in the preparation of this document.

American Concrete Institute
116R Cement and Concrete Terminology
121R Quality Management System for Concrete Construction
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete
211.3R Guide for Selecting Proportions for No-Slump Concrete
211.4R Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash
211.5R Guide for Submittal of Concrete Proportions
212.3R Chemical Admixtures for Concrete
221R Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete
221.1R State-of-the-Art Report on Alkali-Aggregate Reactivity
225R Guide to the Selection and Use of Hydraulic Cements
232.2R Use of Fly Ash in Concrete
304R Guide for Measuring, Mixing, Transporting, and Placing Concrete
305R Hot Weather Concreting
308R Guide to Curing Concrete
311.4R Guide for Concrete Inspection
311.5 Guide for Concrete Plant Inspection and Testing of Ready-Mixed Concrete
325.9R Guide for Construction of Concrete Pavements and Bases
325.11R Accelerated Techniques for Concrete Paving
325.12R Guide for Design of Jointed Concrete Pavements for Streets and Local Roads
504R Guide to Joint Sealants for Concrete Structures
544.1R State-of-the-Art Report on Fiber Reinforced Concrete
546R Concrete Repair Guide

American Association of State and Highway Transportation Officials
M 31 Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
M 55 Steel Welded Wire Fabric, Plain, for Concrete Reinforcement
M 148 Liquid Membrane-Forming Curing Compounds for Curing Concrete
M 220 Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements
M 301 Joint Sealants, Hot-Poured, for Concrete and Asphalt Pavements

ASTM International
A 185 Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete
A 615 Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
C 150 Standard Specification for Portland Cement
C 309 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
C 595 Standard Specification for Blended Hydraulic Cement
C1157 Standard Performance Specification for Hydraulic Cement
C 1260 Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
C 1583 Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-Off Method)
D 2628 Standard Specification for Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements
D 6690 Standard Specification for Joint and Crack Sealants, Hot-Applied, for Concrete and Asphalt Pavements
E 965 Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique

These publications may be obtained from these organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094
(248) 848-3800
www.concrete.org
ACI COMMITTEE REPORT

American Association of State and Highway Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001
www.aashto.org

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
www.astm.org

8.2—Cited references


American Concrete Pavement Association (ACPA), 1999b, “Ultra-Thin Whitetopping,” *Information Series IS100.02*, Skokie, Ill.


American Concrete Pavement Association (ACPA), 2000d, “Iowa Whitetopping—20 Years and Still Going Strong,” *Concrete Pavement Progress*, V. 36, No. 2, Skokie, Ill.


Hall, K. T.; Darter, M. I.; and Seiler, W. J., 1993, “Improved Design of Unbonded Concrete Overlays,” Proceedings of the 5th International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, West Lafayette, Ind.


